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THE ELECTRICAL RESISTANCE OF MANGANESE AMALGAMS

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ABSTRACT. The variation with temperature of the electrical resistance of a series of manganese-mercury amalgams of known composition has been studied over the range −78 to 340° C., and an attempt has been made to correlate the electrical data with previous measurements of the magnetic susceptibility of similar amalgams.

§ 1. INTRODUCTION

IN a recent paper Bates and Tai(1) have described experiments on the magnetic properties of dilute amalgams of manganese with mercury. They found that in all cases pronounced changes of the magnetic susceptibility occurred with rise in temperature, and that temperature-hysteresis phenomena were present. With the more concentrated amalgams there was at first a decrease in the value of the diamagnetic susceptibility as the temperature rose from 20° C. to approximately 80° C., followed by an increase continuing to temperatures as high as 250° C., after which there was a rapid decrease in the diamagnetic susceptibility until a steady value was reached at about 300° C. On cooling from temperatures above 300° C. the diamagnetic susceptibility decreased slightly as the temperature fell until 120° C. was reached, after which there was generally a rapid increase until the initial value at room temperature was attained. In some cases the initial value was not always reached upon cooling and the magnetic behaviour was to some extent determined by the rate at which the amalgam was cooled. It seemed desirable to find whether the magnetic changes thus observed were accompanied by peculiarities in the electrical behaviour of the amalgams. A search of the literature showed that in general the electrical properties of amalgams have only been investigated over somewhat more restricted ranges of temperature than had been employed in the above magnetic measurements, and, in particular, no record of resistance measurements with manganese amalgams was found. Presumably this is in part due to the fact that manganese amalgams have hitherto been regarded as difficult to produce and readily oxidized in the presence of air.

Bates and Tai also made preliminary investigations of the variation of the magnetic susceptibility of pure mercury with temperature, using for the purpose three different specimens. Two of these specimens showed that the diamagnetic susceptibility decreased with rise in temperature from 20 to 340° C., but the third showed little change. More recently, Bates and Ireland$^{(3)}$ have specially examined the behaviour of several specimens of pure mercury and found that the numerical value of the diamagnetic susceptibility of all the specimens decreased with rise of temperature from $0{\cdot}168 \times 10^{-6}$ c.g.s. units per gram at 18° C. to $0{\cdot}161 \times 10^{-6}$ at about 340° C. It is known, of course, that the resistance of pure mercury increases in a regular manner over a similar temperature range.

§ 2. EXPERIMENTAL PROCEDURE

It was realized at the outset that, on account of the difficulty of handling the more concentrated amalgams, experiments would have to be confined to specimens containing not more than 0·15 per cent of manganese by weight. The amalgams were produced by electrolysis of a concentrated solution of manganese chloride, the anode being a platinum plate immersed in a solution of manganese sulphate within a porous pot, and the cathode a pool of mercury of known mass which was continually stirred. An amalgam of known concentration was obtained by passing a current of 0·5 amp. for a fixed time. In preliminary experiments, Analar mercury which was not redistilled was used, but in later experiments the mercury was first distilled in vacuo at a high temperature. Air was bubbled through the distilled mercury for 24 hr., and it was then filtered and finally redistilled at a low temperature by the Hulett$^{(2)}$ method. It was magnetically tested for impurity before use. The freshly prepared amalgam was quickly washed with distilled water and poured into the conductivity apparatus described below, a small amount of water being intentionally left with the amalgam to prevent oxidation of the surface. This method of producing a known concentration of manganese is not entirely satisfactory, since some of the manganese may redissolve during electrolysis, but it was considered adequate for the present purposes, and the fact that very little gas was generated at the cathode indicated that the concentrations given below are reasonably accurate.

The pyrex glass conductivity apparatus is shown diagrammatically in figure 1. In the main it consisted of a horizontal capillary U tube provided with the limbs *A* and *B* at the ends. The effective length of the capillary was approximately 160 cm. and its bore about 1·5 mm. Ground glass joints were provided at *G* and *G′* and served to carry the tubes *ab* and *a′b′* through which platinum potential and current leads were taken to the specimen. The potential leads passed along the whole lengths of *ab* and *a′b′* and emerged through the lower ends as shown. The current leads emerged through the small holes *c* and *c′* in the sides of the tubes and were bound to the outsides of the tubes by platinum wire; in this way the relative positions of the electrical contacts were adequately fixed. The leads passed through ebonite plugs, waxed in position, at the upper ends of the tubes. The limbs *A* and *B* could be evacuated through the side tubes *F* and *F′*, connected through drying tubes to a Hyvac pump. A suitable clamp held apart the ends of the capillary tube near the limbs to facilitate handling of the apparatus. The conductivity apparatus could be placed in a special furnace constructed of copper plates $\frac{1}{4}$ in. thick and $2\frac{3}{4}$ in. wide, such as are normally used for electrical bus bars, forming a chamber of length 90 cm., width 7 cm., and depth 2 cm. with highly conducting walls. Upon two layers of asbestos paper over the copper a single layer of Glowray tape was wound and the whole was thoroughly lagged. One end of the furnace was specially extended to hold the two limbs *A* and *B* of the conductivity apparatus and an end plate of the extension could be removed to permit introduction of the capillary tube. When the conductivity apparatus was in position, *A* and *B* were packed around with asbestos wool. The temperature of the capillary was measured by two thermometers inserted longitudinally into the furnace through holes in the ends. The heating filament was centre-tapped and the two halves connected in parallel to the supply mains, one half also being in series with a variable rheostat whose adjustment enabled the temperatures in the two halves of the furnace to be equalized.

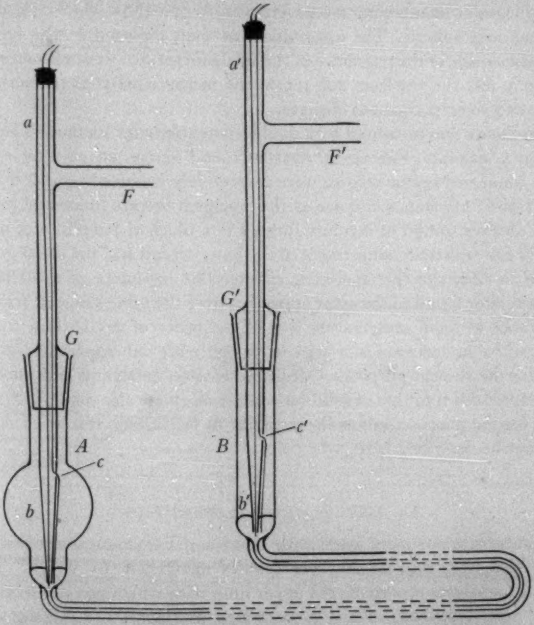

Figure 1. Conductivity apparatus for measurements with amalgams.

Immediately after the introduction of the amalgam into the conductivity apparatus the latter was evacuated, placed in the furnace, and heated to about 360° c. This ensured complete removal of water and occluded gas, while the amalgam boiled vigorously and was thoroughly mixed. The apparatus was then removed from the furnace and tilted so that the whole of the amalgam collected in the bulb *A*, whereupon, by careful manipulation, an unbroken thread of homogeneous amalgam was run into the capillary tube. The apparatus was now connected through a drying tube to a nitrogen cylinder, a simple barometer tube acting as a safety valve in maintaining a pressure of nitrogen above the amalgam slightly greater than atmospheric. The apparatus was then replaced in the furnace and measurements made of the resistance of the amalgam thread. It was found practically impossible to mix the amalgam and repeat the measurements as the surfaces in *A* and *B* showed some permanent changes.

The resistance was measured by a double-potentiometer method. The potential falls across a standard 100,000-Ω. resistance and across an adjustable standard resistance connected in one circuit, were respectively balanced against those across a standard 10-Ω. resistance and across the amalgam thread connected in a second circuit. A shallow trough of mercury formed in a block of paraffin wax provided a particularly fine resistance-adjustment in the latter circuit and the usual precautions were taken to eliminate thermoelectric effects. The resistance of a thread of pure mercury was later found in the same apparatus over the same range of temperature. The resistance at room temperature was of the order of 0·5 Ω. and could easily be measured to an accuracy of 1 part in 50,000 with our apparatus, an accuracy sufficient for the present purposes. Measurements on amalgams and pure mercury at temperatures down to that of solid carbon dioxide were also made, using a special apparatus for the purpose, but as these appear to provide no results of significance they will not be described here.

§ 3. EXPERIMENTAL RESULTS

Final measurements were made with a series of five amalgams whose concentrations varied from 0·01 to 0·15 per cent of manganese by weight. The most concentrated amalgam represents the upper limit with which one can work with the apparatus here described. More concentrated amalgams are lacking in homogeneity and cannot be satisfactorily introduced into the capillary tube; moreover, it is extremely difficult to clean the apparatus when once it has contained a very concentrated amalgam. The results of measurements with the five amalgams are shown graphically in figure 2, in which is plotted the difference ΔR between the resistances of the pure mercury and the amalgam threads, divided by the resistance R of the pure mercury thread, at each of a series of known temperatures. The upper temperature in these experiments is, of course, limited by the boiling point of mercury at the particular nitrogen pressure used in the apparatus. All the curves show the resistance of an amalgam thread to be less than that of a pure-mercury thread, and, with the possible exception of the curve for the weakest amalgam, the curves show the same general form. The value of $\Delta R/R$ remains constant over a small temperature range above that of the room and then shows a sudden change. The higher the concentration of the amalgam, the higher appears to be the temperature at which this change occurs. The initial value of $\Delta R/R$ also appears steadily to increase with increase in manganese content, but while we are confident that the curves of figure 2 accurately represent the nature of the temperature variation, we do not consider these initial values to be entirely reliable.

Following the above sudden change, the value of $\Delta R/R$ appears to increase at a uniform rate over an appreciable range of temperature and eventually becomes fairly constant. The higher the concentration of the amalgam, the higher the temperature at which the constant value is attained and the more restricted its range. It would appear that if the use of more concentrated amalgams had been possible the numerical value of $\Delta R/R$ would have been found steadily to increase from about 100° C. until the boiling-point of mercury was reached. In all cases there was found a marked increase in the numerical value of $\Delta R/R$ as the boiling-point of mercury was approached. This increase is not shown in some of the graphs because the measurements were not recorded at sufficiently high temperatures.

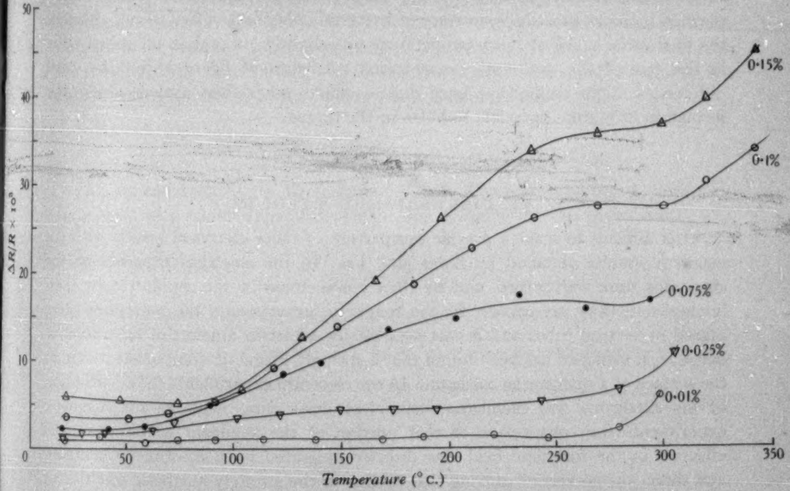

Figure 2. Curves showing how the ratio, $\Delta R/R$, the difference in resistivities of pure mercury and manganese amalgam divided by the resistivity of pure mercury, varies with temperature. Concentrations of manganese stated in per cent by weight. (The resistance of the amalgam is less than that of pure mercury.)

In view of the pronounced temperature-hysteresis phenomena recorded by Bates and Tai, a careful search for allied resistance phenomena was made. In the preliminary experiments with Analar mercury considerable hysteresis changes were found in the case of concentrated amalgams. The resistance of an amalgam thread in process of cooling was always slightly lower than the resistance of the same thread at a given temperature when its temperature was being raised, except in the region of 110° C. where the heating and cooling curves merged. Moreover, when the temperature of the amalgam was being raised there was a sudden drop in the value of $\Delta R/R$ between 60 and 80° C., but during cooling the value of $\Delta R/R$ fell almost to zero at 60° C. and remained very low until room-temperature was reached, when the initial value was again reached after the apparatus had remained at room-temperature for many hours. In the final measurements with specially purified mercury practically no trace of hysteresis phenomena was found, although the final value of ΔR at room-temperature was slightly lower than the initial value in the case of the two most concentrated amalgams of figure 2, but the small differences might easily have been due to effects other than hysteresis, e.g. the formation of minute, invisible bubbles in the thread.

§4. DISCUSSION OF RESULTS

It is difficult to make a precise comparison of these electrical results with the magnetic results obtained by Bates and Tai. In the electrical experiments the amalgams were well mixed, and by their confinement in the capillary tube their homogeneity was preserved. In the magnetic experiments the amalgams were placed in vertical tubes and it was possible for a certain amount of separation to occur; e.g. evidence has been found that a strongly magnetic component moves to the surface of a manganese amalgam. In the electrical experiments the constitution of the amalgams was calculated from electrolysis data, while in the magnetic experiments the constitution of that portion of the amalgam which was most effective in the magnetic field was directly measured by a colorimeter method, and there was no way of proving that mixing of the strongly magnetic constituent at the surface and the main body of the amalgam, although unlikely, did not occur at high temperatures, giving rise to an amalgam of concentration greater than that measured directly.

There are, however, certain points which definitely justify comment. For instance, the initial decrease in magnetic susceptibility with rise in temperature of all the amalgams is not accompanied by a corresponding change in the value of $\Delta R/R$. Again, the steep rise in the value of $\Delta R/R$ with further increase in temperature occurs when the diamagnetic susceptibility is more or less constant or increasing slowly, and there is a considerable increase in $\Delta R/R$ between 300 and 350° C. in the case of the concentrated amalgams while the susceptibility here remains more or less constant. Finally, with pure amalgams, there is practically no temperature hysteresis of the electrical resistance, although the magnetic susceptibility shows the marked temperature hysteresis and quenching phenomena which were discussed by Bates and Tai.

The initial decrease of the diamagnetic susceptibility with rise in temperature above that of the room might be ascribed to the manganese atoms or ions becoming increasingly free of the surrounding mercury atoms so that the pronounced paramagnetic properties of manganese could be exhibited, and as this paramagnetism is due to uncompensated spins in the incomplete electron shell we should expect it to be unaccompanied by marked resistance changes. If this process does not continue indefinitely, then the paramagnetic susceptibility should decrease with further rise in temperature, while that part of the resistance which is partly electrolytic in character should decrease (i.e. $\Delta R/R$ would increase) because of the decrease in the viscosity of mercury. The magnetic changes manifested by the large fall in diamagnetic susceptibility between 250 and 300° C. are presumably due to further changes in the association between manganese and mercury atoms, and when these are completed the value of $\Delta R/R$ again changes rapidiy because of the rapid fall in the viscosity of mercury as the boiling point is approached.

§ 5. ACKNOWLEDGEMENTS

We are indebted to the Government Grants Committee of the Royal Society for a grant with which apparatus used in this investigation was purchased.

REFERENCES

(1) Bates, L. F. and Tai, L. C. *Proc. phys. Soc.* **49**, 230 (1937).
(2) Hulett, G. A. *Phys. Rev.* **33**, 307 (1911).
(3) Bates, L. F. and Ireland, A. W. *Proc. phys. Soc.* **49**, 642 (1937).

THE MAGNETIC PROPERTIES OF SILVER AMALGAMS

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ABSTRACT. The Gouy method has been employed in the measurement of the magnetic susceptibilities of silver amalgams containing 0 to 5 per cent of silver by weight; the method was found unsuitable for gold amalgams. Silver enters into solution in mercury as if it possessed a molar susceptibility of about -18×10^{-6} c.g.s. units in very dilute amalgams and -77×10^{-6} in more concentrated ones, instead of the molar susceptibility $-21{\cdot}6 \times 10^{-6}$ usually found for solid silver.

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§ 1. INTRODUCTION

In an examination of the magnetic properties of mercury amalgams, Bates and Tai(1) showed that the added metal and mercury in an amalgam did not form a simple mechanical mixture as had previously been suggested. For example, manganese, which in the solid state has a molar susceptibility of 648×10^{-6} c.g.s. units, exhibits a molar susceptibility of $13{,}700 \times 10^{-6}$ when in dilute solution in mercury. Again, bismuth, which is strongly diamagnetic in the solid state is strongly paramagnetic when in dilute solution in mercury. In the case of copper, there seems to be little change when dissolved in mercury, for Bates and Tai found that in the latter circumstances the molar susceptibility was about $-7{\cdot}3 \times 10^{-6}$ instead of the value $-5{\cdot}4 \times 10^{-6}$ normally associated with solid copper; at the same time it must be recorded that it is extremely difficult to obtain copper entirely free from iron, and the experimental results were subject to a correction for ferromagnetism which was large and somewhat uncertain. It was therefore decided to examine the behaviour of gold and silver amalgams in mercury. Davies and Keeping(2) previously worked with gold amalgams, but as the value they obtained for the susceptibility of pure mercury is in error, we concluded that their results were mainly of qualitative interest.

As the susceptibility of pure mercury at room temperature may now be taken as $0{\cdot}1680 \times 10^{-6}$ e.m.u. per gram to a high degree of accuracy, our measurements have been referred to this value as standard. The pure mercury used in these experiments was first bubbled with air, washed in dilute nitric acid and water, and distilled in a quartz high temperature still. It was then bubbled with air for 24 hours, filtered, and redistilled in a form of apparatus like that described by Hulett(3) in a stream of air at a pressure of 1 to 2·5 cm. of mercury to remove any of the more volatile metals. Our amalgams were prepared both by electrolysis and by boiling metal foil with mercury in an evacuated tube, the purest gold and silver available being used. The pure mercury and the amalgams were tested for ferromagnetic impurity, but none was found.

The apparatus used in the susceptibility determinations consisted of a uniform pyrex tube which was approximately half-filled with mercury or amalgam before being evacuated and sealed. The tube was suspended vertically from one arm of a sensitive balance between the pole pieces of an electromagnet so that the line of centres passed through the surface of the liquid. On account of symmetry there was no measurable magnetic pull upon the glass tube itself when the field was excited, a point checked by measurements with an empty tube. As mercury is diamagnetic there was an additional downward force upon the liquid when a field H was excited and the usual Gouy formula could be used, giving

$$\delta m_{\mathrm{Hg}} g = \tfrac{1}{2} \alpha k_{\mathrm{Hg}} H^2 \qquad \text{......(1)}$$

and

$$\delta m_a g = \tfrac{1}{2} \alpha k_a H^2 \qquad \text{......(2),}$$

where δm_{Hg} and δm_a were the additional weights in the balance pan required to restore equilibrium when the tube of area of cross section α respectively contained pure mercury and amalgam. Hence $k_a = k_{\mathrm{Hg}} \delta m_a / \delta m_{\mathrm{Hg}}$, assuming the field H to be constant. H was of the order of 10,000 oersteds for experiments at room-temperature, and its constancy was systematically checked by a calibrated Grassot fluxmeter, and by the values of δm_{Hg} for a standard tube.

§ 2. EXPERIMENTAL RESULTS

The results for silver amalgams are shown in figure 1 where are plotted the ratios of k_a/k_{Hg} for a series of amalgams of known concentrations. As the density of all amalgams containing up to 2 per cent of silver is very approximately 13·55 g./cm.^{3}, this ratio is the same as that of the corresponding mass susceptibilities. The curve shows an initial portion in which the quantity of dissolved silver has little effect upon the susceptibility. At higher concentrations there is a more or less linear increase in diamagnetic susceptibility with concentration.

The points marked χ on the graph were obtained from measurements with amalgams produced by the complete denudation of a known solution of silver nitrate by electrolysis. In general, we found that silver amalgams so prepared were unsatisfactory, particularly at lower concentrations, where very erratic variations in the susceptibility with concentration were observed. We found also that those impurities which may be removed by high temperature distillation of mercury produced much more pronounced effects with electrolytically prepared amalgams than with those prepared by heating silver foil in mercury in vacuo. On the other hand, it is only possible to prepare homogeneous amalgams of high concentration by electrolysis. If we consider that m g. of silver of mass susceptibility χ_M are amalgamated with $(100-m)$ g. of mercury, giving an amalgam of mass susceptibility χ_a, we have

$$100\chi_a = m\chi_M + (100-m)\,\chi_{\mathrm{Hg}}$$

and, on differentiation, we get

$$\chi_M = 100\,d\chi_a/dm + \chi_{\mathrm{Hg}}.$$

In the initial portion of the curve, then, $\chi_M = \chi_{\mathrm{Hg}}$ approximately, whence the molar susceptibility of silver is $-108 \times 0{\cdot}168 \times 10^{-6} = -18{\cdot}1 \times 10^{-6}$ unit. In the region where the linear relation between diamagnetism and concentration exists we find that

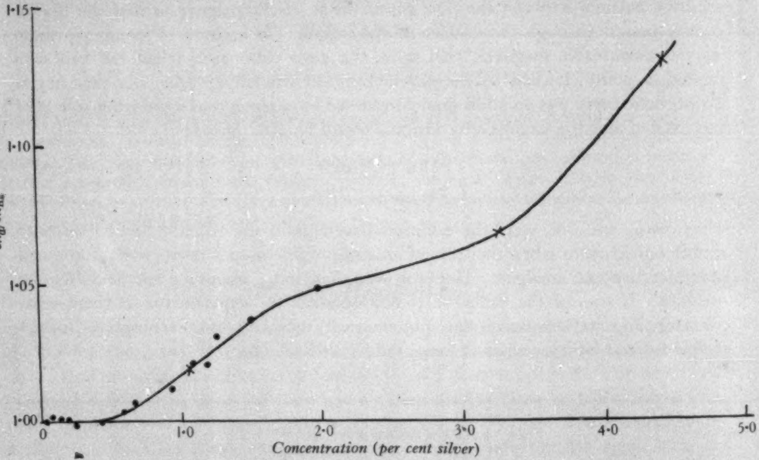

Figure 1. Ratio of susceptibility of silver amalgam to susceptibility of pure mercury at 20° C. as function of silver content by weight.

$$100\,d\chi a/dm = -0{\cdot}546 \times 10^{-6},$$

whence

$$\chi_M = (-0{\cdot}546 - 0{\cdot}168) \times 10^{-6},$$

or the molar susceptibility of the silver added in this region is $-77{\cdot}1 \times 10^{-6}$ unit. The value usually given for the susceptibility of silver in bulk is $-21{\cdot}6 \times 10^{-6}$.

Our experimental results for gold amalgams were disappointing, for we found that in this case the Gouy method could not be used, as the amalgam rapidly resolved itself into a gold-rich and a gold-free portion, the former lying at the bottom of the tube and outside the field. Such separation also occurred with silver amalgams, but it took place very much more slowly, and, as the amalgams were thoroughly mixed immediately before values of δm_a were recorded, we do not think that our results are in error due to lack of homogeneity. Measurements are therefore being made by a translational method using pole-pieces of the Fereday(4) type.

These measurements will take some time to complete, and as one of us (A. W. I.) is taking up an appointment overseas, it is considered desirable at this stage to publish the results so far obtained. It is particularly important to use this method for an investigation of the temperature dependence of the susceptibility of silver amalgams, as there is an interesting change in physical properties at 80° C.

§ 3. ACKNOWLEDGEMENTS

The experiments were made with an electromagnet and other apparatus purchased from grants made by the Government Grants Committee of the Royal Society, and A. W. I. is indebted to the Department of Scientific and Industrial Research for a maintenance allowance.

REFERENCES

(1) Bates, L. F. and Tai, L. C. *Proc. phys. Soc.* **48**, 795 (1936).
(2) Davies, W. C. and Keeping, E. S. *Phil. Mag.* **7**, 145 (1929).
(3) Hulett, G. A. *Phys. Rev.* **33**, 307 (1911).
(4) Fereday, R. A. *Proc. phys. Soc.* **43**, 383 (1931).

THE LONGITUDINAL PIEZOELECTRIC EFFECT IN ROCHELLE-SALT CRYSTALS

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ABSTRACT. The piezoelectric coefficient d_{11}' relating the compressional stress in any direction to the resulting polarization in the same direction is given from well-known transformation formulae. When the x' axis, with respect to which d_{11}' is defined, makes equal angles with the three crystallographic axes, this longitudinal effect is a maximum. A plate cut with its normal in this direction is designated as "*L*-cut". Experiments made with a number of such plates are described, including their use as microphones and as sound-emitters at acoustic frequencies, as piezoelectric resonators for thickness vibrations, and as sources of ultrasonic waves. By a static method the value of d_{11}' was found to be from 5400×10^{-8} to 6300×10^{-8} electrostatic units.

§ 1. INTRODUCTION

SINCE the earliest quantitative measurements on the piezoelectricity of Rochelle salt(1), experimenters have made use of the fact that a piezoelectric polarization parallel to any one of the crystallographic axes can be produced by a compressional stress at 45° with the other two axes. In recent years this fact has led to many investigations on Rochelle-salt resonators employing longitudinal vibrations, and to various practical applications. The effect is commonly known as the *transverse piezoelectric effect*, the electric polarization being at right angles to the direction of compression. By proper orientation of the specimen it can be realized with all piezoelectric crystals.

The existence of a *longitudinal* piezoelectric effect in Rochelle salt, characterized by a polarization in the same direction as the mechanical pressure, seems to have been generally overlooked,* in spite of the fact that the Curies(4) may have utilized it in their discovery of piezoelectricity in this substance. Moreover, Voigt(5) subsequently derived general equations from which such an effect necessarily follows.

§ 2. THEORY

Voigt's general equation for the longitudinal effect(5), with slight change in notation, is as follows:

$$\begin{aligned} P = -\Pi\, [&l^3 d_{11} + m^3 d_{22} + n^3 d_{33} + l^2 m\,(d_{21} + d_{16}) + l^2 n\,(d_{31} + d_{15}) + m^2 n\,(d_{32} + d_{24}) \\ &+ m^2 l\,(d_{12} + d_{26}) + n^2 l\,(d_{13} + d_{35}) + n^2 m\,(d_{23} + d_{34}) + lmn\,(d_{14} + d_{25} + d_{36})] \\ = -&d_{kk}'\Pi \qquad \text{......(1)}, \end{aligned}$$

where P is the component of polarization parallel to Π caused by pressure Π, and

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* The author confesses to having shared in this oversight(2). Even very recently R. Hiltscher(3) stated categorically that thickness vibrations cannot be excited in a Rochelle-salt plate.

l, m, and n are the direction cosines of both P and Π, while the ds are the piezoelectric coefficients with respect to the crystallographic axes. Equation (1) holds for all piezoelectric classes, and shows that a longitudinal effect is in general present for *all* directions of pressure so long as the direction cosines are not such as to make the expression vanish.

The present discussion has to do with the digonal holoaxial (or rhombic hemihedral) class, to which Rochelle salt belongs, involving only the piezoelectric coefficients d_{14}, d_{25}, and d_{36}. However, the equations are equally applicable to all piezoelectric classes which do not possess any other than these three coefficients. For such classes, the {polarization, stress} equations reduce simply to

$$-P_x = d_{14} Y_z, \quad -P_y = d_{25} Z_x, \quad -P_z = d_{36} X_y,$$

the polarization parallel to one of the crystallographic axes being in each case given in terms of a shearing stress in a plane normal to the axis in question. For rhombic crystals the x, y, z axes are identical with the crystallographic a, b, c axes(5). All that remains of Equation (1) is then the last term.

Any cut made from a crystal belonging to one of these classes will show a longitudinal effect so long as the direction cosines l, m, and n are all different from zero. The maximum effect occurs when the product lmn is a maximum, so that $l = m = n = 1/\sqrt{3}$ and the normal to the plate makes equal angles with the three crystallographic axes.

It should be stated that in the class to which Rochelle salt belongs either end of any two of the crystallographic axes may be taken as positive. The positive end of the third axis is then determined by the requirement that the x, y, and z axes shall form a right-handed coordinate system. The crystal may be rotated 180° about any one of the three crystallographic axes without any change in magnitude or sign of the piezoelectric coefficients.

§ 3. OBLIQUE CUTS

For an oblique cut in any orientation we adopt a system of orthogonal axes designated as x', y', and z'. The x' direction is taken as that in which the longitudinal effect is to be investigated; a plate cut with its thickness in this direction may be termed an X'-cut plate. So far as the longitudinal effect is concerned the directions of the other axes are arbitrary.

For generality, let it be assumed that the x', y', and z' axes have been chosen with the direction cosines indicated in table I:

Table I

	x'	y'	z'
x	l_1	l_2	l_3
y	m_1	m_2	m_3
z	n_1	n_2	n_3

By the use of the transformation equations given by Voigt⁽⁵⁾, and by Davies⁽⁶⁾ and Stamford⁽⁷⁾ all of the piezoelectric coefficients with respect to the new axes can be expressed. Three such equations are given below. When the pressure and polarization are parallel to x', giving the longitudinal effect, we have from the last term in equation (1):

$$d_{11}' = l_1 m_1 n_1 (d_{14} + d_{25} + d_{36}) \qquad \ldots\ldots(2).$$

When the pressure is parallel to y' and the polarization to x', giving the transverse effect,

$$3d_{12}' = (l_1 m_2 n_2 + m_1 n_2 l_2 + n_1 l_2 m_2)(d_{14} + d_{25} + d_{36}) + l_2 l_3 (d_{25} - d_{36}) + m_2 m_3 (d_{36} - d_{14}) + n_2 n_3 (d_{14} - d_{25}) \qquad \ldots\ldots(3).$$

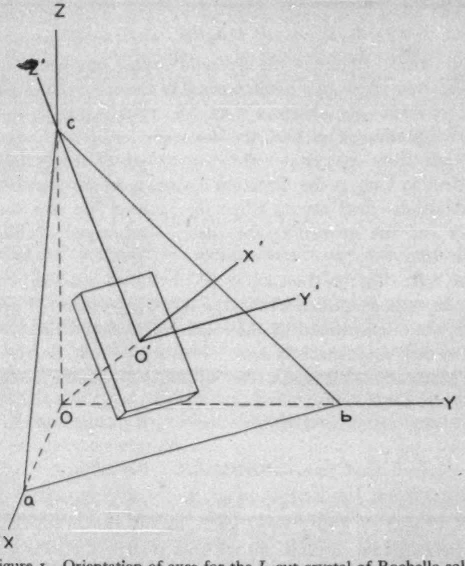

Figure 1. Orientation of axes for the *L*-cut crystal of Rochelle salt.

When the pressure is parallel to z' and polarization to x', giving the transverse effect,

$$3d_{13}' = (l_1 m_3 n_3 + m_1 n_3 l_3 + n_1 l_3 m_3)(d_{14} + d_{25} + d_{36}) - l_2 l_3 (d_{25} - d_{36}) - m_2 m_3 (d_{36} - d_{14}) - n_2 n_3 (d_{14} - d_{25}) \qquad \ldots\ldots(4).$$

§ 4. THE *L* CUT

The only oblique cut with which the experiments here described are concerned is that X' cut for which the x' axis makes equal angles with the three crystallographic axes, since, as was indicated in § 2, the longitudinal effect is a maximum for this orientation. We shall refer to it as the *L* cut. The x' axis makes an angle of 54° 44′ with the x, y, and z axes, as shown in figure 1, in which the equilateral triangle *abc* represents the plane of the *L* cut. The y' axis is taken in the xy plane, at 45° to the x and y axes and hence parallel to *ab* and perpendicular to the z axis. The z' axis is such as to make a right-handed orthogonal system with x' and y'. The edges of the plate are cut parallel to the y' and z' axes.

The direction cosines now have the following values:

$$l_1 = m_1 = n_1 = 0{\cdot}5774; \quad -l_2 = m_2 = 0{\cdot}7071; \quad n_2 = 0; \quad l_3 = m_3 = -0{\cdot}4083; \quad n_3 = 0{\cdot}8165.$$

For the fundamental piezoelectric coefficients we may use the widely quoted values of Pockels:

$$d_{14} = 1000 \times 10^{-8} \text{ e.s.u.}, \quad d_{25} = -165 \times 10^{-8} \text{ e.s.u.}, \quad d_{36} = 35 \times 10^{-8} \text{ e.s.u.}$$

From them we obtain

$$d_{11}' = 168 \times 10^{-8} \text{ e.s.u.}, \quad d_{12}' = -10 \times 10^{-8} \text{ e.s.u.}, \quad d_{13}' = -157 \times 10^{-8} \text{ e.s.u.}$$

If on the other hand we call $d_{14} = 10{,}000$, a value which seems reasonable from the results obtained by more recent investigators, we have $d_{11}' = 1900$, $d_{12}' = -10$ (this coefficient depends on d_{36} alone), $d_{13}' = -1890$.

§ 5. OBLIQUELY CUT CRYSTALS AS RESONATORS

When obliquely cut crystals are used as resonators, it is desirable to compare observed values of frequency with those computed from the elastic constants. The best available complete data for the latter are those of Mandell(8), obtained by a statical method. For a bar with its length parallel to x' we find for Young's modulus, derived from equation (4) on p. 627 of Mandell's paper(8), p. 758 of Voigt's book(5),

$$1/s_{11}' = 1{\cdot}70 \,.\, 10^{11} \text{ dyne/cm}^2$$

For a plate with its normal in the x' direction vibrating in thickness(9), we use the coefficient c_{11}', which from the equation on p. 596 in Voigt's book(5) is found to be

$$c_{11}' = 2{\cdot}99\ (10^{11}) \text{ dyne/cm}^2$$

From these values and the density (1·77), the wave constants, in metres of electromagnetic wave-length per millimetre of crystal in the direction of vibration, are found to be 193 for the bar and 146 for the plate.

§ 6. PLATES USED IN EXPERIMENTS

From a single crystal three *L*-cut plates designated as *A*, *B*, and *C* were prepared. At various stages they were reduced in size or subdivided in the manner indicated by subscripts. In all cases the edges were approximately parallel to the x', y', and z' axes defined in § 4. Errors in orientation may have amounted to as much as 2°. Table 2 contains the list of plates with their dimensions, their observed fundamental frequencies of compressional vibration in the x' direction (the applied electric field being also in this direction), and their wave constants *h* in metres per millimetre.

Table 2

Plate no.	x' (mm.)	y' (mm.)	z' (mm.)	f (kc./sec.)	h (m./mm.)
A	—	Irregular: area about 7·5 cm^2			
A_1	3·52	19·9	25·7	605	141
A_1'	3·26	19·5	25·5	—	—
A_3	3·42	9·05	9·05	605	145
A_4	1·93	11·9	11·9	1070	145
B_1	7·78	33	25	267	144
B_2	7·4	27	22	278–284	143–146
B_3	7·2	Irregular: area about 2·5 cm^2			
C	19·0	5·68	6·19	78·8	200

§ 7. STATIC TESTS

The only piezoelectric coefficient measured was d_{11}'. As was to be expected, the anomalies that are so conspicuous in the behaviour of X-cut Rochelle-salt plates are prominent here also, owing to the presence of d_{14} in equation (2). Plates A and A_1' were subjected to varying pressures in the x' (thickness) direction, the resulting charges being measured with a ballistic galvanometer. Thin tinfoil electrodes were cemented to the plates with a very small amount of Canada balsam dissolved in xylol, after the plates had been carefully ground and polished. The results for plate A are shown in figure 2. The maximum value of d_{11}', obtained from the slope of the dotted line, is 6300×10^{-8} e.s.u. The temperature was 21° C. The phenomena are

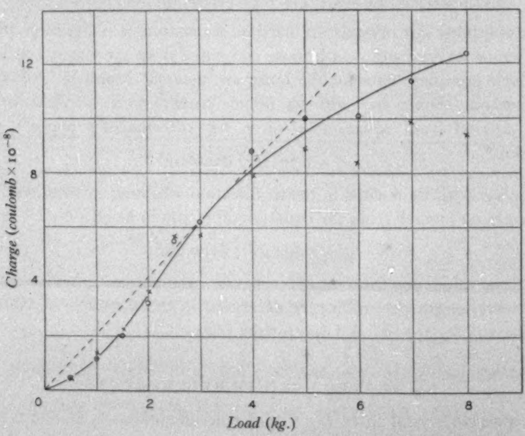

Figure 2. Polarization curve for plate A. Circles represent application of load, and crosses, release.

of essentially the same character as those observed by others with *X*-cut 45° plates for the transverse effect. This is to be expected, since the value of d_{11}' is due almost wholly to the influence of d_{14}. For the same reason it was not surprising to find that the value of d_{11}' at 23° C. was twice as great as at 20°, and that at 28° C. it had sunk to about one-tenth of the value at 20°. Plate *A* showed pronounced fatigue: after the application of 8 kg. for 6 hr. the activity was reduced to $\frac{1}{4}$ of its former value. In one day it recovered to $\frac{1}{2}$ of the latter.

After an interval of three months, plate *A* had become plate A_1' and was again tested, at a temperature of 21° C., giving a curve similar to that shown in figure 1. The maximum value of d_{11}' was found to have been reduced to 5400×10^{-8} e.s.u. By substitution of this quantity in equation (2), d_{14} was found to be $28,000 \times 10^{-8}$ e.s.u.; for plate *A* the value was $32,500 \times 10^{-8}$ e.s.u. These figures are of the same order of magnitude as the large value, $26,000 \times 10^{-8}$ e.s.u., recorded by Schulwas-Sorokin(10). It may be said in general that those sources of error that depend on faulty orientation, treatment, mounting, and electrodes always tend to make the observed piezoelectric coefficient d_{14} too small: the largest observed values are likely to be nearest the truth.

Observations of the dielectric constant k_{11}' were made with plate A_1' also. From 200 V./cm. upward, saturation was approached, and a reversal of field gave slightly different values. At small fields the mean value of k_{11}' was 1400. From this the value of k_{11} parallel to the x axis is found to be 4200. This is of the same order of magnitude for this very inconstant constant as that observed in the x direction with the same fields by Oplatka(11), Sawyer and Tower(12), and others.

§ 8. ACOUSTIC TESTS

Plates A_1 and B_3 gave comparable results, although B_3 (a portion of B_1, part of which was destroyed by overvoltage) had in static tests shown piezoelectric and dielectric coefficients only about one-tenth as great as those of A_1. The tests were merely for the purpose of demonstrating the longitudinal piezoelectric effect in Rochelle salt at acoustic frequencies. The plate under test, with tinfoil electrodes, lay exposed on a wooden base. It was found to function either as a microphone or as a sound-emitter, being more effective at high than at low frequencies. All natural frequencies of both plates were far above audibility.

In the sound-emission tests, made while the crystal was emitting a note of constant pitch, the sound-field close to the crystal was explored by means of a stethoscope and found to be strongest immediately above the plate, though considerable sound was given off from two opposite corners also. The transverse piezoelectric coefficients were computed from Pockels' data for the two diagonal directions and found to be 11·2 and −278; and when for d_{14} the value 10^{-4} was assigned instead of 10^{-5}, the computed values became 750 and −2640.

§ 9. RESONATOR TESTS

The plate under test was connected in the grid circuit of a calibrated r.f. oscillator, and its various frequencies of response observed by the "click" method. In many cases nodal regions were mapped by means of dust patterns. Many frequencies were observed with each plate. As is usually the case with thickness vibrations in quartz plates that are not ground with high precision, so also here in the neighbourhood of the computed frequencies for thickness vibrations (plates *A* and *B*) there were many resonance points close together. Nevertheless, the dependence of these response regions upon thickness made identification fairly certain, so that mean values for thickness vibration could be recorded. Such values are listed in table 2 for those plates that were thus examined. Agreement is satisfactory between the observed wave constant h in m./mm. and the computed value 146 (see § 5). Certain other frequencies having a linear dependence on thickness were recorded also; they are probably attributable to shear modes of vibration.

Crystal *C* was in the form of a rod with its length parallel to x'. The electrodes were placed opposite the ends of the rod. The frequency for lengthwise vibration recorded in table 2 has been corrected for cross-section by Rayleigh's formula, the correction amounting to about ½ per cent. The wave constant, 200 m./mm., is somewhat greater than the value 193 computed in § 5. This may be due in part to the fact that the wave-propagation was not strictly parallel to the length of the rod. Powder sprinkled over the vibrating rod (magnesium flashlight powder gave best results) indicated a single nodal plane which was not normal to the length of the rod but roughly at 60° to the length (x' axis) and parallel to the z' axis. This seems to be related to the oblique nodal line$^{(13, 14, 15)}$ observed by Meissner in *X*-cut quartz plates undergoing lengthwise vibrations parallel to the y axis, which he attributed to the tendency for wave-propagation to take place in the direction of maximum or minimum elasticity. In order to investigate this point, a computation was made of the elastic coefficient s_{11}' for various directions, with the result that the maximum value was found to lie in the *ac* plane, at an angle of about 42° with the *a* axis. This direction is inclined at about 35° to the x' axis, and a plane normal to it agrees fairly well with the observed nodal plane. Before definite conclusions can be drawn, however, it will be necessary to repeat the experiment with other specimens. The discrepancy between the observed and calculated values of the wave constant is in accordance with the above hypothesis.

§ 10. ULTRASONIC TESTS

This portion of the work has been carried only to the point of exploring the possibilities of Rochelle salt as a source of ultrasonic waves. A cylindrical glass tube 6 cm. in diameter with its axis vertical, containing water or toluol, was closed at the bottom by a brass diaphragm 0·14 mm. thick. The optical system was similar to that of Debye and Sears$^{(16)}$. Diffraction bands could be projected on to a screen or observed by the aid of an eyepiece. In the later tests the cylindrical vessel was replaced by a flat-walled projection cell.

In the experiments with water, the crystal was provided with an upper brass electrode about 1·5 mm. thick, soldered to the outside of the diaphragm. It was found that the material and thickness of the lower electrode had but little effect on the results. On the other hand, for maximum amplitude of vibration at which the diffraction bands became visible, the values of frequency were such as to indicate that the upper electrode and the diaphragm played an important part in determining the fundamental and overtone frequencies of the system. Bands including the second order were observed, in water, at about 1330, 2290, and 3370 kc./sec., with a plate 2·65 mm. thick. A quartz plate 2·4 mm. thick cemented to the outside of the diaphragm showed only first-order diffraction with the same voltage (around 200 volts).

Much better results were obtained when the crystal was laid above the diaphragm, immersed in toluol, with tinfoil electrodes. Diffraction spectra up to the fifth order were observed up to 3900 kc./sec., which was as far as the tests extended. They correspond to the fundamental and various overtones of the crystal.

At the same voltage, the number of orders observed and their distinctness were about the same with Rochelle salt as with quartz when the crystal was immersed in the liquid. It is not yet clear why Rochelle salt did not give as good results as quartz at much lower voltages, considering the much larger piezoelectric coefficient. It is possible that at these high frequencies the effective coefficient is very much less than when it is measured statically. It may at least be stated, however, that owing to its low cost the Rochelle-salt *L*-cut plate deserves consideration as a generator of ultrasonic waves of moderate intensity. In the course of these experiments it was found that the plates will stand voltages up to about 1000 v./cm. without breakdown, when immersed in an insulating liquid.

REFERENCES

(1) Pockels, F. *Abh. Ges. Wiss. Göttingen*, **39**, 183 (1894).
(2) Cady, W. G. *Proc. Inst. Radio Engrs, N.Y.*, **18**, 2141 (1930).
(3) Hiltscher, R. *Z. Phys.* **104**, 672 (1937).
(4) Curie, P. and J. *C.R. Acad. Sci., Paris*, **91**, 383 (1880).
(5) Voigt, W. *Lehrbuch der Kristallphysik* (Leipzig, 1910), pp. 99, 836–42, 849, 872.
(6) Davies, R. M. *Phil. Mag.* **16**, 97 (1933).
(7) Stamford, N. C. *Proc. Inst. Radio Engrs, N.Y.*, **25**, 465 (1937).
(8) Mandell, W. *Proc. roy. Soc.* A, **116**, 623 (1927).
(9) Cady, W. G. *Physics*, **7**, 248 (1936).
(10) Schulwas-Sorokin, R. D. *Z. Phys.* **73**, 700 (1932).
(11) Oplatka, G. *Phys. Z.* **34**, 296 (1933).
(12) Sawyer, C. B. and Tower, C. H. *Phys. Rev.* **35**, 269 (1930).
(13) Meissner, A. *Z. Techn. Phys.* **7**, 585 (1926).
(14) Straubel, H. *Phys. Z.* **32**, 222 and 379 (1931).
(15) Straubel, H. *Hochfrequenztech. u. Elektroakust.* **38**, 14 (1931).
(16) Debye, P and Sears, F. W. *Proc. Nat. Acad. Sci., Wash.*, **18**, 409 (1932).

AN APERIODIC AMPLIFIER FOR INVESTIGATING THE WAVE-FORM OF ATMOSPHERICS

By H. C. WEBSTER, Ph.D., F.Inst.P.

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ABSTRACT. An amplifier is described which produces a voltage amplification of about 120, with a maximum output of about 200 v. r.m.s., the amplification being independent of frequency between 50 c./sec. and 5×10^5 c./sec. This amplifier was designed for use with an aperiodic aerial circuit for investigating the wave-form of atmospherics, suitable means of calibration being provided. Disturbances due to fluctuations in a.-c. supply mains are eliminated by means of a push-pull arrangement.

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§ 1. INTRODUCTION

Various investigators(1,2,3) have described apparatus for the registration of the wave-form of atmospherics. The amplifier described herein has been designed by the writer for an investigation of the wave-form and energy-content of atmospherics at Melbourne, in which several workers have been associated. It incorporates the new principles of amplifier design developed by von Ardenne(4) and others, and is compact and easy to construct. It has been used successfully in analysis of transients in piezo-electric crystals and in switchgear, as well as with atmospherics(5).

§ 2. DETAILS OF THE AMPLIFIER

The circuit diagram of the amplifier and the values of components used are given in figure 1. In all the diagrams the valves are of standard American types and the resistances are of the carbon type. Although this type of resistance is somewhat crude and has a large temperature coefficient, it has the advantage of being non-capacitative as well as non-inductive, and is capable of carrying relatively large currents. The load resistance of each of the output valves needs to have a rather larger power-dissipating capacity (5 w.) than those normally used in wireless receivers.

The general design is somewhat similar to that of von Ardenne(4), but push-pull amplification is used after the first stage. The valve V_1 is a reversing valve, with zero gain. The remaining valves are connected in pairs, the grid swings of corresponding valves being equal and opposite, and the final output is of push-pull type, suitable for direct application to a pair of deflecting plates of the cathode-ray tube. An important property of this arrangement is that variations in anode voltage due to fluctuations of the mains affect both valves of a pair equally and hence do not, except in extreme cases, produce any deflection of the cathode-ray beam. Thus no

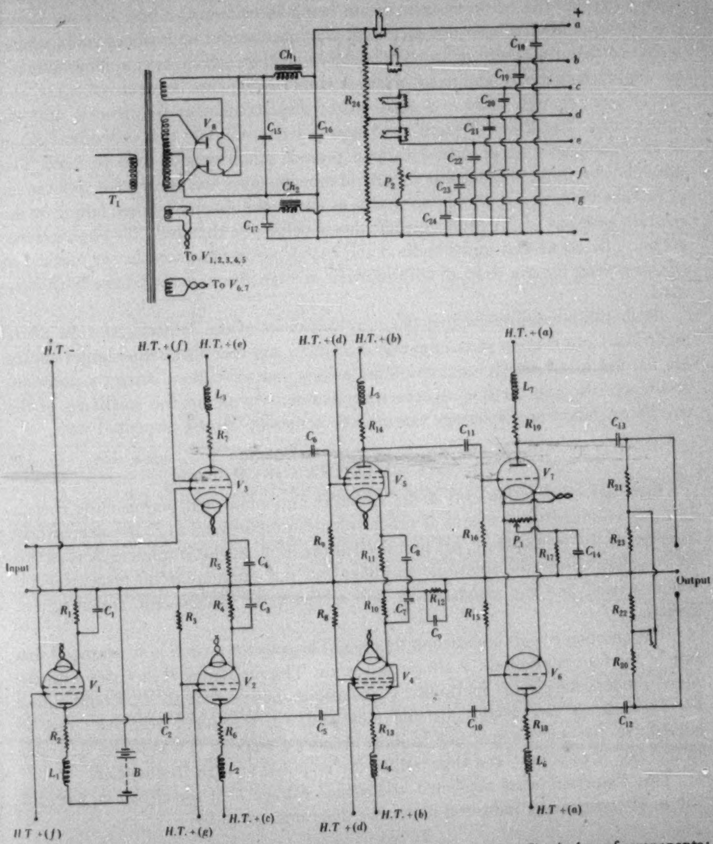

Figure 1. Amplifier circuit, with power pack shown separately for clarity. Particulars of components: Valves V_1 to V_8, Radiotrons 36, 36, 36, 38, 38, 10, 10, and 523 respectively. Resistances R_1 to R_{24}, 10^3, 2×10^3, 10^5, 10^3, 10^3, 10^4, 10^4, 10^5, 10^5, 10^3, 10^3, 5×10^2, 10^4, 10^4, 10^5, 10^5, 10^3, 10^4, 10^4, 2×10^5, 2×10^5, $2{\cdot}5 \times 10^4$, $2{\cdot}5 \times 10^4$, and 5×10^4 Ω. respectively. Potentiometers P_1, P_2, 10^3 and 10^5 Ω. respectively. Condensers C_1 to C_{24}, $1{\cdot}5 \times 10^{-3}$, 0·5, 10^{-3}, 10^{-3}, 0·5, 0·5, 10^{-3}, 10^{-3}, 25, 0·5, 0·5, 0·5, 0·5, 0·5, 25, 4, 8, 25, 8, 8, 8, 4, 8, 4, and 4 μF. respectively. Inductances L_1 to L_7, 0·5, 1·8, 1·8, 1·8, 1·8, 2·2, and 2·2 mH. respectively. Chokes Ch_1, Ch_2, 60 and 30 H. respectively. Battery, 120 V. Transformer 230 V. to 5 V., 900 V. (centre-tapped), 6·3 V. and 7·5 V.

voltage-regulation device is required. The anode voltage of valve V_1 is supplied from a battery, the current consumption being about 2 mA.

The amplifier has been designed to give a linear output up to about 200 V. r.m.s., which suffices for nearly full-scale deflection on the cathode-ray oscillograph, and to amplify equally all sinusoidal voltages with frequencies between 50 c./sec. and 500 kc./sec., though there is a small phase displacement at frequencies near the upper limit. The lower of these two limits is set by the fact that individual pulses of an atmospheric never appear to have periods much greater than 10^{-3} sec. The upper limit is set by the fact that very rapid movements of the fluorescent spot cannot at present be recorded photographically, as the total light energy then falling on the relevant portions of the photographic film is below the threshold for photographic action. The choke-resistance method and cathode-resistance-condenser method of compensating for the drop of amplification at high frequencies(4) have both been used.

It should be mentioned that the stray capacities of the cathode-ray tube plates and connexions thereto amount to about 20 $\mu\mu$F., and therefore rather larger chokes are needed in the anode circuits of the output pair of valves, since the cathode-resistance bridging method is here inapplicable. Owing to the smallness of the overall amplification, interstage electrostatic screening can be dispensed with.

§ 3. THE ANTENNA CIRCUIT

Included in the same unit as the amplifier and connected permanently thereto is the antenna circuit by means of which voltages proportional to E, the electric field strength of the atmospheric, are produced at the input of the amplifier. A steel box of 16 gauge covers the aperiodic amplifier and the antenna circuit, excepting the antenna itself and the resistance R, and serves as an electrostatic and magnetic screen.

The antenna circuit is shown in figure 2. The selector switch is so arranged that one of the four condensers is always in circuit. The resistance R in series with the aerial renders the circuit aperiodic. Calculations showed that 10 Ω. would suffice for aperiodicity and would give the most uniform frequency response; but on account of the interference due to local broadcast stations it was found desirable to increase R to 10^4 Ω., and thus reduce the response at high frequencies.

This distortion being neglected, the output voltage V of the circuit is, with the values of components indicated under the diagrams, given by

$$V = E\, h_0 \frac{C_0}{C' + C_0},$$

where C_0 is the capacity of the aerial, h_0 its equivalent height, and C' the capacity of whichever of the condensers $C_1 \ldots C_4$ is in circuit. With the aerial at present in use (L-type, 15 m. high, 60 m. long) C_0 was found to be (270 ± 20) $\mu\mu$F.

The equivalent height h_0 for purposes of the present measurements is defined by

$$h_0 = \frac{\int C(x)\, h(x)\, dx}{\int C(x)\, dx},$$

where $C(x)\,dx$ represents the capacity to earth of an element dx of the aerial distant x from the end, and $h(x)$ is the height of the element in question. With an L-type aerial with a long horizontal portion, it is clear that h_0 is nearly the mean height of the horizontal portion. This has been confirmed experimentally.

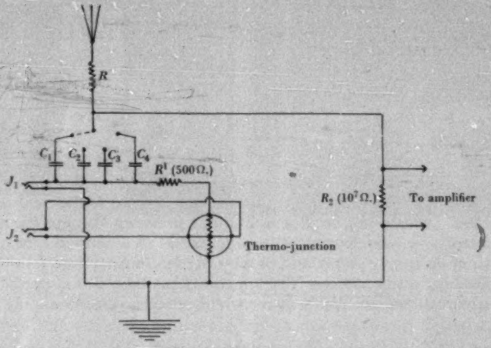

Figure 2. Antenna circuit. Capacities of condensers, 114, 345, 2000, and 4750 μμF. respectively.

The overall amplification of the apparatus (about 120) is checked periodically by injecting an e.m.f. of 2 V. at 1000 c./sec. from a test oscillator across the Ayrton-Perry wound resistance R', figure 2, with a Cambridge 10-mA. thermo-junction in series. The voltage is determined by measuring the thermo-electric e.m.f. with a Tinsley portable galvanometer, the system having been previously calibrated on d.c.

§ 4. ACKNOWLEDGEMENTS

I wish to thank Prof. T. H. Laby, F.R.S., for suggesting the investigation of wave-form and energy content of atmospherics. This work has been carried out as part of the programme of the Radio Research Board of the Council for Scientific and Industrial Research of the Commonwealth of Australia, and the author wishes to thank the Board for permission to publish the paper.

REFERENCES

(1) Watson Watt, R. A., Herd, J. F. and Bainbridge-Bell, L. H. *The Cathode-ray Oscillograph in Radio Research*, pp. 101–110, also 75–80 (1933). H.M. Stationery Office.

(2) Norinder, H. *Proc. Inst. Radio Engrs, N.Y.*, **24**, 587 (1936).

(3) Appleton, E. V. and Chapman, F. W. *Nature, Lond.*, **134**, 968 (1934); *Proc. roy. Soc.* A, **158**, 1 (1937).

(4) von Ardenne, M. *Wireless Engr*, **13**, 59 (1936).

(5) Laby, T. H., Nicholls, F. G., Nickson, A. F. B. and Webster, H. C. *Nature, Lond.*, **139**, 837 (1937).

APPLICATIONS OF THE MODULATING ELECTRODE OF TELEVISION CATHODE-RAY TUBES IN INVESTIGATIONS OF THE WAVE-FORM OF ATMOSPHERICS

By H. C. WEBSTER, Ph.D., F.Inst.P.

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ABSTRACT. An apparatus is described which, when applied to the modulating electrode of an electron-lens cathode-ray oscillograph tube, prevents the electron-beam current from flowing except when a deflecting voltage in excess of a defined minimum is present between one pair of deflecting plates, and/or for a predetermined time following the occurrence of a specified deflecting voltage. The apparatus has been found useful for visual and photographic observations on the non-recurrent electric transients as produced by atmospherics.

§1. INTRODUCTION

During an investigation in Melbourne of the wave-form of atmospherics, in which several workers have been associated, the author has designed an electrical circuit by means of which the brightness of the fluorescent spot of a cathode-ray tube can be related to the deflection of the spot along one of the electrical axes of the tube. The particular relation chosen was: (*a*) zero brightness for deflections less than about 2 mm. (adjustable); (*b*) rapidly increasing brightness for deflections slightly exceeding this amount; (*c*) maximum possible brightness for deflections exceeding the threshold by 50 per cent.

A formidable difficulty in design has been the reduction of time-lag between brightness and deflection, since rapidly changing deflections arise from atmospherics. This time lag has been reduced to less than 10^{-5} sec. The unit may conveniently be known as the *deflection-modulation unit*.

A subsidiary trigger circuit* used in some cases maintains the brightness of the spot for a specified time after any deflection greater than a specified limit has occurred. This unit is somewhat sluggish in action and cannot be used alone. The two units have been used for visual and photographic observations of the wave-form of atmospherics. Examples of the photographs so obtained are shown in figure 1; others are included in a recent communication to *Nature*⁽¹⁾. The chief virtue of the apparatus is that it leads to economy of film; with it no photographic action takes place in the intervals between atmospherics.

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* The unit was designed by the writer and constructed in collaboration with Mr A. F. B. Nickson, B.Sc.

The units have been used in investigations of transients in piezo-electric crystals and switch-gear, and it is suggested that they would form a useful adjunct to the cathode-ray direction-finder of Watson Watt, Herd and Bainbridge-Bell(2), and in other studies of non-recurrent electrical transients.

Figure 1 (*a*). Deflection-modulation unit only.

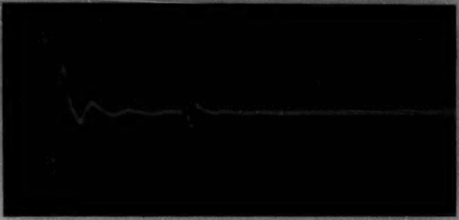

Figure 1 (*b*). Both units.

§ 2. DETAILS OF DEFLECTION-MODULATION UNIT

The circuit of the deflection-modulation unit is shown in figure 2. The power pack has been omitted, being of standard type. The point A of the output is connected to the modulating electrode of a cathode-ray tube of the electron-lens type(3). At present a Cossor tube, type 3271 J, is used, in which the cylinder round the cathode acts as a modulating electrode. This electrode controls the current in the cathode-ray beams, the current increasing with a positive swing of the voltage of this electrode. The voltage of the point B is so adjusted that the beam current is normally zero. Since the beam-accelerating voltage used is 4000 v., the two 1-μF. condensers in the output circuit have each to stand a voltage-drop of about 2000 v., the resistances shown serving to divide this equally between the two condensers.

The input jack is connected to the output jack of the aperiodic amplifier described in the preceding paper (see figure 1 of that paper), so that about one-tenth of the amplifier output voltage (i.e. the voltage applied to the deflecting plates of the tube) is applied to the grids of the valves V_1 and V_2. These serve together as a rectifier unit which gives a negative output whenever the output voltage of the aperiodic amplifier exceeds a few volts in either direction. The grids of the valves are biased so that the anode current is normally zero, in fact they are given about 1 v. more negative bias than suffices to attain this condition. When the output voltage of the aperiodic amplifier is finite but less than 10 v. in either direction, the grid of one of the valves becomes positive and the other negative. Since, however, the positive voltage is less than 1 v., still no anode current flows. When the amplifier output exceeds 10 v., anode current flows in one of the valves, and consequently the grid of V_5 acquires a small negative voltage, and hence the anode of V_5 and thus the modulating electrode become more positive. As the output voltage of the amplifier increases these voltage swings increase very rapidly, so that for an output instantaneous e.m.f. of about 15 v. the grid swing of V_5 suffices to prevent any anode

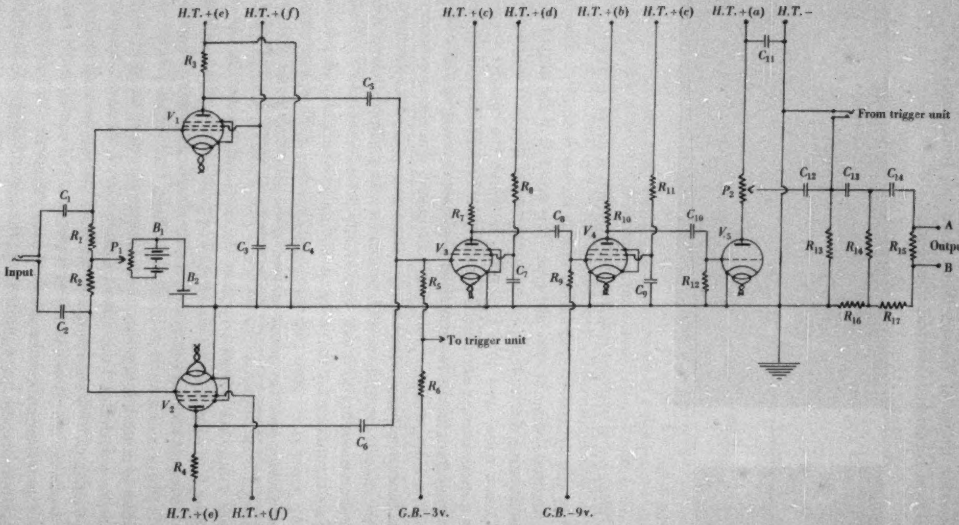

Figure 2. Deflection-modulation unit. Particulars of components: Valves V_1 to V_5, Radiotron 57, 57, 58, 57, and 56 respectively. Resistances R_1 to R_{17}, 10^6, 10^6, 5×10^4, 5×10^4, 10^6, 10^5, 10^4, 10^4, 10^5, 10^4, 10^4, 10^5, 10^6, 2×10^6, 10^6, 3×10^6, and 3×10^6 Ω. respectively. Potentiometers P_1, P_2, $1{\cdot}5 \times 10^4$ and 10^5 Ω. respectively. Condensers C_1 to C_{14}, 0·5, 0·5, 8, 4, 0·5, 0·5, 8, 0·5, 8, 0·5, 8, 0·5, 1, and 1 μF. respectively.

current from flowing in this valve, and thus there is no further increase in the voltage change of the modulating electrode. By means of the potentiometer P_2 the amount of the limiting voltage swing can be adjusted so that the spot is just brought up to full brightness, excessive positive voltage causing defocusing. This adjustment and the adjustment of the voltage of the point B are, of course, interdependent.

The potentiometer P_1 allows adjustment of the threshold deflection, i.e. the minimum deflection of the spot actually visible. In practice it is found desirable to set this at about 2 or 3 mm. to eliminate very small atmospherics from distant sources, and local man-made static.

The amplifying stages V_3, V_4 are designed to give as small a time-lag as possible in the operation of the unit. Thus stray capacities are reduced to a minimum, and the coupling resistances are kept small. As the amplification is much greater than is really necessary, it is found that with rapid pulses there is considerably greater delay in switching off the spot than in switching on.

§ 3. TRIGGER UNIT

The circuit of the trigger unit is shown in figure 3. The power pack, being of standard design, is omitted. The input jack A is connected through a key to the appropriate terminal of deflection-modulation unit. The actuating pulse due to the atmospheric, initially negative, is amplified and converted to a positive pulse by the valve V_1. This positive pulse is applied to the grid of the thyratron V_2, and provided it is large enough an arc will occur in V_2. The resultant sudden drop in anode voltage of V_2 gives a large negative bias to the grid of V_4 and hence prevents anode current from flowing in that valve, making its anode, and thus the modulating

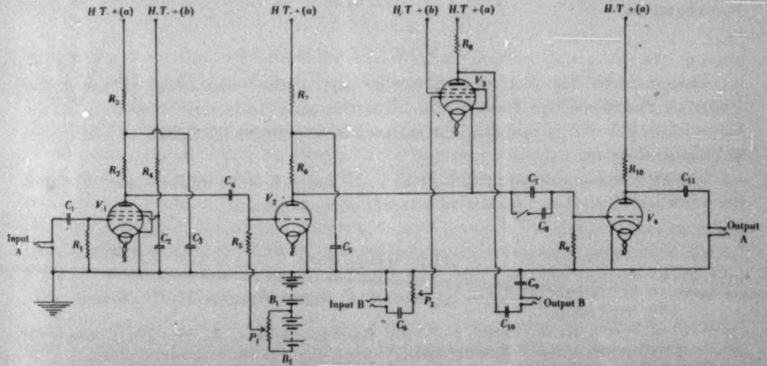

Figure 3. Trigger unit. Particulars of components: Valves V_1 to V_4, Radiotron 57, 885, 57 and 56 respectively. Resistances R_1 to R_{10}, 5×10^5, 10^5, 10^5, $2{\cdot}5 \times 10^5$, 10^5, 10^4, 5×10^5, 10^5, 2×10^5, and 10^5 Ω. respectively. Potentiometers P_1, P_2, 10^4 and 10^5 Ω. respectively. Condensers C_1 to C_{11}, 0·1, 0·5, 8, 0·1, 4, 0·5, 10^{-2}, 5×10^{-3}, 0·1, 0·1 and 0·5 μF. respectively.

electrode of the cathode-ray tube, more positive. To reduce multiplicity of controls the output resistance is fixed at a value found by trial to give satisfactory results, the necessary fine adjustment being made by altering the voltage of the point B, figure 2. Owing to the relatively short time-constant of the grid coupling circuit, this change in anode voltage persists for only a short time, the spot of the cathode-ray tube actually remaining bright for about 0·05 sec. with the switch open or 0·3 sec. with the switch closed.

The arc in V_2 soon discharges the 4-μF. condenser to below 10 V., when the arc stops. The condenser then recharges through the $5 \times 10^5\,\Omega$. resistance, and as it does so the anode voltage of V_2 rises to its original value, the rise having a time constant of about 2 sec. It should be noted that by altering the grid bias of V_2 it is possible to control the minimum size of atmospheric necessary to operate the unit, and thus to select the larger atmospherics from among the many that operate the deflection-modulation unit.

The valve V_3 is a keying valve, the 1000-c./sec. voltage introduced at the input jack *B* being transmitted to the output jack *B* only during the existence of the arc in V_2 and part of the subsequent recharging of the condenser. For it is only during these periods that the anode and screen grid of V_3 are positive with respect to its cathode and hence that the valve is able to perform its normal functions. The automatic keying is required for various subsidiary purposes in the wave-form investigations.

§ 4. ACKNOWLEDGEMENTS

This research has been carried out as part of the programme of the Radio Research Board of the Council for Scientific and Industrial Research of the Commonwealth of Australia, and the author wishes to thank the Board for permission to publish the paper.

The author also wishes to thank Prof. T. H. Laby, F.R.S., under whose direction the work has been done, for his advice and encouragement.

REFERENCES

(1) Laby, T. H., Nicholls, F. G., Nickson, A. F. B. and Webster, H. C. *Nature, Lond.*, **139**, 837 (1937).

(2) Watson Watt, R. A., Herd, J. F. and Bainbridge-Bell, L. H. *The Cathode-ray Oscillograph in Radio Research*, pp. 126–86 (1933). H.M. Stationery Office.

(3) Cossor Booklet B 26 A.

ON THE USE OF ROTATING PARALLEL-PLANE GLASS BLOCKS FOR CINEMATOGRAPHY AND FOR PROJECTION WITH CONTINUOUSLY MOVING FILMS

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ABSTRACT. A theory is developed of the method of taking cinema pictures of rapidly moving objects by projecting their images on to a continuously moving film with the aid of a moving glass element. The comparative advantages of different forms of rotating element are considered, and the magnitude of the outstanding errors are determined. Suggestions for improving the method are made.

§ 1. INTRODUCTION

Within the last few years a method of photographing rapidly moving objects on a continuously travelling film has been developed, and several different ways of accomplishing this aim by the employment of a revolving slab of glass have been described in French and American patent specifications. It has been claimed(1) that as many as 2500 exposures per second can be made by this method. I propose to consider the theory of the method and to ascertain the most efficient form for the plane-parallel-surfaced slab.

The function of this slab, which is mounted between the lens and the travelling film, is in virtue of its constant angular velocity to convert a stationary image formed directly by the lens into an image as nearly as possible sharply focused on the film and moving with the same velocity.

In its simplest form the slab has a single pair of parallel surfaces, but this clearly implies a great waste of film. For instance if the slab has to rotate through 30° while a point on the film travels from the centre to the edge of the exposure gate, only the first and the last 30° of a half-revolution are effective; two-thirds of the film are not utilized. This result points to the desirability of discarding the glass block having only one pair of opposing parallel surfaces in favour of one having two, three or more pairs of parallel surfaces. Even a ten-sided block may be found necessary for the best results, provided that the focal length of the lens leaves room enough for its use.

§ 2. DISPLACEMENT THEORY

In a previous paper[(2)] an expression was obtained for the displacement or side-stepping of a ray caused by traversing a glass plate of thickness t and refractive index μ. If χ is the angle the ray in air makes with either surface, formula (2) of that paper, when the first-order term $t(1-1/\mu)\tan\phi$ is included, gives for the displacement d, measured along the second surface of the plate, the value

$$d=t\left\{\frac{\mu-1}{\mu}\tan\chi+\frac{\mu^2-1}{2\mu^3}\tan^3\chi-\frac{3(\mu^2-1)^2}{8\mu^5}\tan^5\chi+\frac{5(\mu^2-1)^3}{16\mu^7}\tan^7\chi\dots\right\} \qquad \dots\dots(1).$$

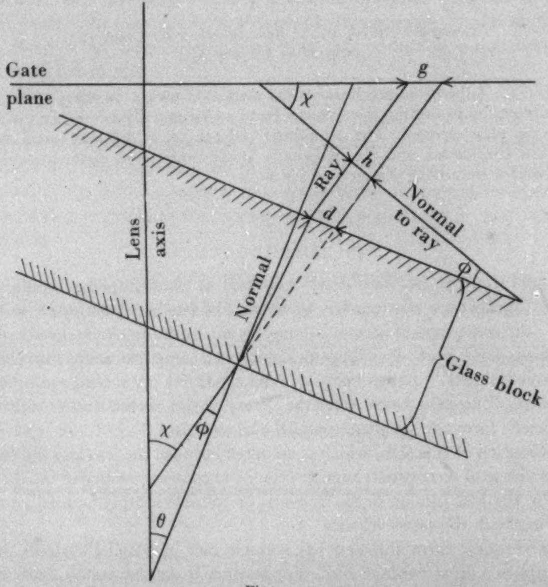

Figure 1.

The terms after the first normally correspond to aberrations. For a given value of d the aberrational effects will obviously be diminished by reduction of the value of $\tan\chi$ and increase of t in about the inverse ratio. Clearly then the glass block should be as thick as is practicable.

I convert the linear side-stepping d of oblique rays along the second surface of the parallel slab into its corresponding value g in the plane of the gate as follows.

If the ray makes an angle ϕ with the optical axis, since this axis is normal to the gate the side-stepping measured perpendicular to the ray is $g\cos\phi$. Similarly it is equal to $d \cos \chi$, since χ is the angle between the ray and the normal to the surface of the slab. Therefore

$$g=\frac{d \cos \chi}{\cos \phi} \qquad \text{......(2).}$$

If the angle ϕ is considered positive when the direction of the ray is obtained by a clockwise rotation from the direction of the optical axis, and if the slab is in a position derived by clockwise rotation through an angle θ from its neutral position (with surfaces parallel to the gate plane) the three angles are connected by the relation

$$\chi=\phi-\theta \qquad \text{......(3).}$$

These equations cover every case when the usual sign conventions are observed. The length g represents the distance of the point in which the actual refracted ray meets the gate plane from the point in which that ray would meet the same plane if the slab were simply removed, so that the ray travels unrefracted to the plane occupied by the gate.

§ 3. HEXAGONAL PRISM

The considerations already mentioned seemed to indicate that either hexagonal or octagonal blocks would be required. In the first case considered I assumed the glass block to be six-sided, 1·92 in. thick, and the refracted index was taken to be 1·50. The gate-opening or picture-pitch is 0·74 in. and the projector lens is of 3·52-in. focus, so that the picture subtends an angle of 12° at the principal point of the lens. This case was investigated partly by trigonometrical calculation and partly by careful drawing. Diagrams on a scale three times larger than the actual apparatus were drawn for three stages of rotation such that $\pm\theta=10°$, 20° and 30°.

For the purpose of graphically illustrating the effects of the rotating parallel slabs upon the image of the exposure gate and the pictures travelling across it, I have assumed the eye to be placed at the first principal point P of the projector lens and to view through each of the three revolving parallel glass slabs in turn an undistorted film picture subtending an angle of 12° at P, and travelling uniformly past the gate, the time for the complete passage being equal to the time the block takes to rotate through 60°. The displacements of the rays which travel from P towards the film along the axis and at 6° on either side of the axis and thus correspond to points at the centre and on the two edges of a picture were determined, these displacements being measured from their ideal positions in the plane of the gate. They were then expressed in terms of the angles they subtend at P. It should be borne in mind that if first-class definition is required in the photographing or screen-projection of pictures, it is desirable that no flicker or blurring which will subtend a visual angle greater than 1 or 2 min. at the eye should be allowed to occur, assuming that the eye is placed at a distance from the picture yielding the original angle of view. Figure 2 is a diagrammatic summary of the results obtained. It shows (compressed vertically to one-third) the various angular distortions or displacements caused by the passage through any one of the three 1·92-in. parallel blocks involved in the hexagonal prism when the angular rotations of the latter are 10°, 20° and 30°.

It will be noticed that for a rotation of 10° a right-hand portion of the following picture appears on the left while a corresponding portion in the right is missing or dark. At 20° two-thirds of the following picture shows on the left, while the corresponding two-thirds of the picture on the right is missing. For a rotation of 30° the picture is distorted by each margin being stretched out by 31 min. of arc, or one-twelfth part of each half picture. In this position the axial ray from the principal point *P* of the lens is virtually split at the sharp intersection of two adjacent surfaces of the block into two symmetrical principal rays. These coincide with a reasonable degree of accuracy (departures − 1·4 min. on the left hand and + 1·4 min. on the right hand) with the centres C_1 and C_2 of two adjacent pictures at once. This implies a duplication of the centre point of the picture with a separation of 2·8 min. The figure also gives the angular displacements for rotations of 40° and 50°: these are clearly the same as those found at 20° and 10° respectively with certain transpositions and changes of sign.

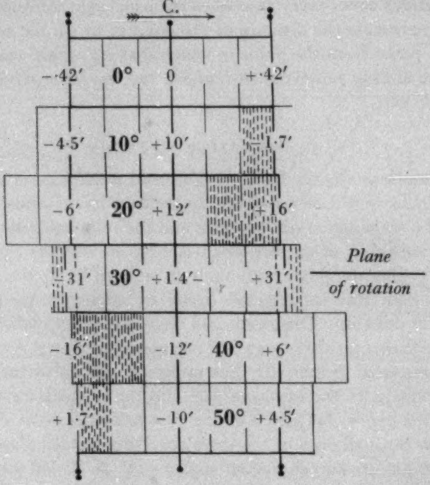

Figure 2.

I have not worked out the displacements corresponding to the lines in figure 2 dividing each picture into three, but their values will be intermediate between those at the centre and the margins. Therefore for a rotation of 10° it will be found that an intermediate or neutral point can be found somewhere in each half of the picture where there is no displacement: a neutral point also exists in the left half for a rotation of 20° and in the right-hand half of each picture for rotations of 40° and 50°.

And now regarding the side rays from the centre of the lens, along which the divisions between pictures should be seen, I must call attention to the arbitrary and indeterminate nature of the apparent displacements produced. First, it is clear that the wider the angle of view the more obliquely do these rays strike the film, so that a very slight movement of the gate to or from the revolving prism, for focusing purposes, will seriously alter their points of incidence on the film picture. Moreover it can be shown that the focal distances from P to the images of points in the picture have undergone a considerable lengthening-out effect owing to their passage through the glass block. The effect of the latter is to apparently throw back the image of the picture to oblique curved focal surfaces, presenting their convexities towards the glass hexagon, and on the opposite side of the gate plane. I mention these matters as they point to a more or less ill-defined image being presented to the projector lens. Any attempt at focusing the picture will have a large influence on the apparent distortion of any points situated near the upper and lower margins of the screen picture.

These facts constitute a very strong objection to the use of any projector lens of focal length less than 4 in., and even then various synchronized shutter devices, such as one for blocking out the central part of the gate when it is occupied by a division between two pictures,* which is subject to a displacement of half a degree, may have to be resorted to.

§ 4. OCTAGONAL PRISM

I now consider the result of increasing the number of flat surfaces of the revolving glass polygon from six to eight, with an increase of its diameter to about 2·70 in. After this, in order to secure working-room for the rotating prism, any further reduction of the flickering can be attained only by substantially reducing the vertical angular diameter of the picture, which I have so far assumed to be 12°. For instance, if the angular vertical height of the picture were reduced to 6° then a glass polygon of a doubled diameter of about 5·4 in. and having 16 flat surfaces might be accommodated. But it would be very difficult to find discs of glass, 5–6 in. in diameter and at least $1\frac{1}{2}$ in. thick, sufficiently homogeneous and well annealed for the forming of such a sixteen-sided prism. Also the practical difficulties attending the correct shaping and polishing of the sixteen faces of such a large glass polygon with sufficient accuracy, in both linear and angular measurements, consistently with well-figured and well-polished plane faces, would be far more than doubled. Moreover, the bulkier the rotating block, the more must its speed of rotation be reduced if its rupture under the great centrifugal forces generated is to be avoided.

For the application of the formulae already derived (which have been utilized alone in this case) I consider seven rays proceeding from the principal point P to the film. Three of these are the axial ray and those proceeding to the middle of the top and the bottom of the picture, inclined at angles of $\pm 6^\circ$ to the axis. The remaining four, which for descriptive purposes may be called the $\pm 4^\circ$ and $\pm 2^\circ$ rays, are chosen to correspond to the partition of each half-picture exactly into thirds in the absence of distortion.

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* This would of course somewhat darken the upper and lower strips of the projected screen pictures.

The angular distortion in minutes of arc is shown diagrammatically in figure 3, where the film's movement is supposed to be horizontally from left to right, so that the vertical distortions given in the tables can be shown horizontally. Here the usually greater width of the horizontal film picture is represented by a vertical width on $\frac{1}{10}$ of the full vertical scale, in order to save room. The eight narrow parallel strips marked *d...d* containing short vertical lines at equal distances apart are lines representing the 6°, 4° and 2° viewing rays on the left of the centre or axial ray, and also the 2°, 4° and 6° viewing rays on the right. These short vertical lines enclosed in the strips *d...d*, etc. thus represent distortionless or correct projection. The longer vertical solid lines show graphically for each of the several prism rotations, 0, 7½°, 15°, 22½°, 30°, 37½° and 45°, the various linear displacements or distortions relative to the seven viewing rays represented by *d...d...d*, which have radiated from the principal point of the lens, been refracted through the octagon, and then intersected the gate plane. The squares marked *g* down each side of figure 3 indicate darkness owing to the obstruction of the metal plate in which the gate opening is cut out, the plate being supposed fixed.

The squares marked *f.p.* with dotted diagonals are each occupied by a sixth part of the following picture, no. 2, while those marked *p.p.* with dotted diagonals are each occupied by one sixth part of the preceding picture. It will be seen that at 7½° and at 37½° of prism rotation only $\frac{4}{6}$ of picture no. 1 is illuminated, together with $\frac{1}{6}$ of the following picture, no. 2, on the left, and $\frac{1}{6}$ eclipsed on the right; at 15° and 30° prism rotation only $\frac{2}{6}$ of the picture is illuminated together with $\frac{2}{6}$ of the following picture, no. 2, on the left, and $\frac{2}{6}$ is eclipsed by the gate plate. In the lowest strip of figure 3, picture no. 2 is shown to have fully taken the place of picture no. 1.

One obvious inference can be drawn from figure 3 and this analysis, namely that a movable gate-opening should be arranged to be central for rotation 0°; to follow the picture, embraced by the refracted 6° viewing rays, up to 15° rotation; then to return to the central position as rotation 22½° is attained; to continue to the left to frame the following film picture no. 2; and then to come back to the central position as the prism rotation reaches zero again. At rotation 15°, instead of the greatest concentration of light taking place on the central $\frac{2}{6}$ only, the three divisions to the right shown obscured in figure 3 would become illuminated together with the central third. But as regards the central position at rotation 22½°, the policy of obstructing the waist of the gate and thus eclipsing the left and right ends of the picture, which show such very marked distortion, is worth serious consideration, for a displacement amounting to about half a degree for rotation 22½° does not recommend itself to onlookers with normal eyesight, since only the central $\frac{2}{6}$ of the screen picture at 22½° rotation can be said to approach the standard of definition expected from ordinary intermittent cinema projection. And here it is worth noting that if the thickness of the glass octagon is reduced to $\frac{77}{78}$ of its present value, the central dark gap shown in figure 2 for 22½° rotation will be closed up, while the distortion for 6° becomes 22′, for 4° becomes 17′ and for 2° becomes 6′. But there would be slight increases in some of the distortions at rotations $7\frac{1}{2}$°, 15°, 30° and $37\frac{1}{2}$°.

So far we have not considered what happens in the way of distortion of position to the top, bottom and the two end margins of the film picture 0·74 in. high and

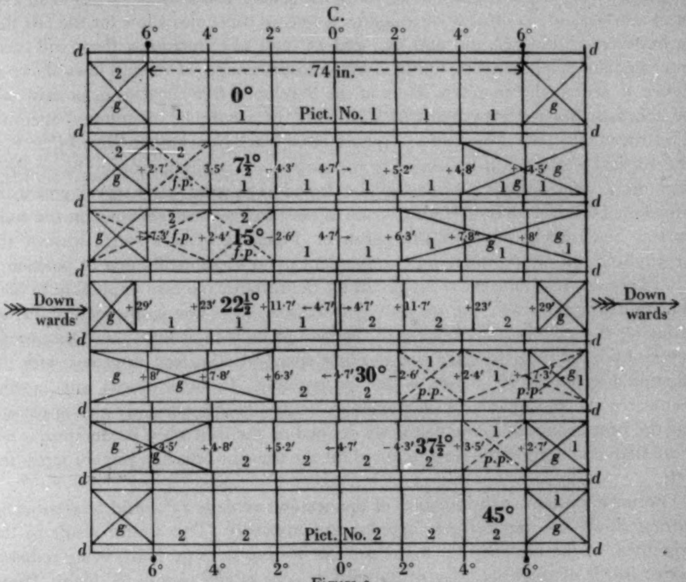

Figure 3.
1 minute = 0·0055 in. and height of gate = ·74 in.

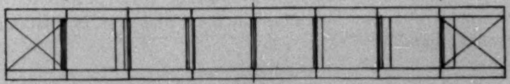

Figure 4.

1·0 in. wide; but whatever the linear displacements or distortions may be down the central vertical waist of the picture, they will certainly be much increased at the four corners of the picture, while the usually straight picture-borders will be curved either towards or away from the centre, according to the signs.

The distortions of position marked in minutes of arc in figure 3 obviously imply more or less up-and-down oscillation, and some very interesting points may be noted, as for instance the varying amount of distortion or oscillation as the rotation of the glass octagon changes from 0° to 22½° and back to 0° again. A point 6° to the left suffers 2·7′ for 7½° rotation, 7·3′ for 15° rotation and 29′ for 22½° rotation—i.e. an over-all scattering of 29′ − 2·7′ or 26·3′.

This, of course, implies oscillation and fuzzy definition, for not only have the displacements of the images for the three successive rotations of 7½°, 15° and 22½° been worked out, as illustrated in figure 3, but we must also allow for the fact that in between 0° and 7½°, 7½° and 15°, and 15° and 22½° rotations, there will occur intermediate displacements, filling in between the images of vertical lines shown in figure 3, so that the complete effect in the developed film negative or positive will be a broad, blurred grey line which will not, as a rule, be of uniform intensity. This means that the images of seven horizontal black lines equally distributed over the vertical white board presented to the camera for projection on to the sensitive film on a much reduced scale will be found registered, after development, as broadened out into nebulous grey bands of uneven greyness, showing on the more or less black background of the negative. Figure 4 gives a rough idea of the broadening-out effects upon lines consequent upon these oscillations of position.

There are two inferences suggested by the facts in the case applicable to both the photographing and the projecting machines. The first is the desirability of reducing the 12° vertical diameter of the field of view to about 8°, and the second is the advisability of keeping the working speed of film feed, together with the rotational speed of the prism, as low as possible. In other words, any moving feature in the instantaneous phenomenon being photographed by this apparatus has the best chance of being distinctly defined on the film when its duration is not more than one sixth of the time required for the transit of the film picture across the gate.

Better definition as the rotation of the octagon exceeds 15° could be secured by cutting down the vertical gate-opening automatically. This would result in the brightness of the top strip (2° high) and the bottom strip (2° high) being reduced to two thirds of the brightness of the middle zone of the picture (8° high). There would be a very substantial gain in definition at the cost of a little light in the upper and lower thirds of the picture, and should the line of demarcation between the upper and lower thirds be at all conspicuous the effect could be softened by arranging the two screening strips somewhat out of the focal plane, as, for instance, $\frac{1}{10}$ in. on the lens side of the gate.

REFERENCES

(1) Tuttle, F. E. *J. Soc. Mot. Pic. Engrs.*, **21**, 474 (1933).
(2) Taylor, H. D. *Proc. phys. Soc.* **46**, 283 (1934).

THE ELECTRICAL RESISTANCE OF FERROMAGNETICS

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ABSTRACT. The resistance of nickel and iron is measured between 20 and 1200° K. From the measurements it is concluded that: (1) the kink in the {resistance, temperature} curve at the Curie point is sharp to within a small fraction of a degree; (2) above the Curie point the {resistance, temperature} curve is concave to the T axis as in a paramagnetic metal such as palladium; (3) the small change in spontaneous magnetization which takes place at low temperatures has a comparatively large effect on the resistance.

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§ 1. INTRODUCTION

In 1930 Gerlach and Schneiderhahn(1) drew attention to the connexion between true magnetization and electrical resistance. In the neighbourhood of the Curie point the application of a magnetic field causes a reduction in the electrical resistance of a nickel wire which is proportional to the change in magnetic energy. Similar results were obtained by the writer for iron and Heusler alloy(2).

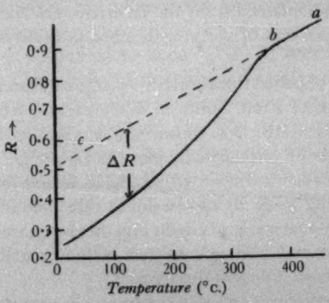

Figure 1.

The {resistance, temperature} curve as given by Gerlach and Schneiderhahn for zero external field is reproduced in figure 1. As the Curie point was approached from the low-temperature side the resistance rose more and more quickly, but the rate of rise of resistance decreased as the metal passed over into the paramagnetic state. On rather incomplete evidence Gerlach concluded that some little distance above the Curie temperature the {resistance, temperature} curve became a straight line *b*, *a*. On extrapolation of this line backwards, the distance ΔR was found to be fairly accurately proportional to the square of the spontaneous magnetization. It was therefore concluded that when the metal entered the ferromagnetic state the resistance fell by an amount which was proportional to the magnetic energy. This leads at once to a very serious difficulty. The extrapolated portion *b*, *c* of the line *a*, *b* cannot represent the course of the {resistance, temperature} curve of a normal, non-ferromagnetic, metal since such a curve must pass through the origin of coordinates.

A further point of interest was raised recently by Svensson(3), who found a discontinuity in the temperature coefficient of resistance of nickel at its Curie temperature. He found this discontinuity to occur in a temperature range as small as $\frac{1}{10}$° C. In view of the growing volume of evidence, from measurements of magnetic energy, that the Curie temperature is not in general a sharply defined point but spreads over some 20 or 30°, this result was very surprising. The difficulties encountered in trying to reconcile the various experiments with one another and with theory seemed to make it desirable to repeat both the Gerlach and the Svensson experiments.

§ 2. METHOD OF MEASUREMENT

Experiments have been carried out both on nickel and on iron. Both metals were obtained from Messrs Adam Hilger, the former having a purity of 99·971 per cent with 0·018 per cent of iron and 0·010 per cent of carbon as the chief impurities. The iron had a purity of 99·96 per cent with silicon and oxygen as the main impurities. In addition a specimen of very pure nickel was obtained from the International Nickel Co.* This contained 99·99 per cent of nickel with 0·009 per cent of carbon as the main impurity.

The resistance was obtained from current-voltage measurements in a specimen in the form of a rod 2 mm. in diameter and 8 cm. long. This was bent into an inverted U as shown at *a*, *b*, *c* and spot-welded at *a* and *c* to long rods of commercially pure nickel *de*, *fg*, figure 2. Two nickel potential leads were mounted parallel to *de* and *fg*, contact with the specimen being made by spot-welding thin platinum wires at *h* and *j*. The whole system was held rigidly together by quartz frames, one of which is shown at *k*. These consisted of four parallel tubes banded together, as shown, by eight quartz rods.

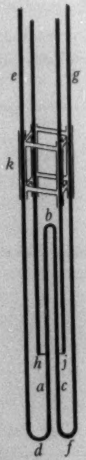

Figure 2.

A potentiometer-controlled current of 0·5 amp. was passed through the specimen, and the potential between *h* and *j* was measured on a Tinsley potentiometer. To correct for stray e.m.fs. in the circuit either the potential was remeasured after reversal of the current, or the potential was measured with and without the current. The two methods always gave identical results. An attempt to avoid this correction altogether, by using fine nickel wires to join the potential leads to the specimen, failed. Firstly, the stray e.m.fs. did not disappear completely, and secondly the thin nickel wires were too brittle after spot-welding. The resistance could be measured, except at temperatures below 0° C., to about 1 part in 2000.

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* Our thanks are due to Mr Wise of the International Nickel Co. who kindly presented us with this specimen through the agency of Messrs Metropolitan-Vickers Electrical Co.

A platinum, platinum-rhodium thermocouple spot-welded midway between *h* and *b* served to measure the temperature. The thermocouple was calibrated in boiling water and melting tin, zinc, aluminium, common salt and copper. The calibration was in good agreement with the figures supplied with the couple by Messrs Johnson Matthey. Thermoelectric e.m.fs. at intermediate temperatures were calculated by means of an interpolation formula. The accuracy of absolute temperature measurement was probably not better than $\frac{1}{2}$ up to 500° C., with perhaps even bigger errors at high temperatures, but changes in temperature of $\frac{1}{10}$° C. could easily be measured. In order to allow for the small e.m.f. (of the order of 1 μv.) produced in the thermocouple by the current, the thermal e.m.f. was remeasured after reversal of the current. This method was preferred to measurement with the current off, since the latter produces a slight temperature rise. Consequently the temperature should be measured with the current on, in order that it may correspond with the potential measurement.

§ 3. FURNACE AND TEMPERATURE CONTROL

The furnace consisted of an evacuated quartz tube with two concentric copper tube liners which served to equalize the temperature along the length of the furnace. The tubes were of 4 mm. in wall-thickness and 30 cm. long, and were heat-insulated from one another by an evacuated annular space. The temperature-gradient in the specimen was only a small fraction of a degree except for temperatures above 700° C., when it amounted to about $\frac{1}{2}$° C. In order to investigate in the neighbourhood of the Curie point of nickel in detail, an automatic furnace control was used. This consisted of a modified Cooke-Swallow regulator(4) made for us by Messrs Metropolitan-Vickers Electrical Co. The platinum thermometer which operated the regulator was between the furnace wall and the outer copper tube. Inside the inner copper tube where the specimen was situated, the temperature could be kept constant to within $\frac{1}{10}$° C. for several minutes and to within $\frac{1}{2}$° C. for indefinite periods.

§ 4. RESULTS

The results are shown in figures 3, 4 and 5 and in tables 1 and 2. They all refer to annealed specimens. The existence of a kink in the {resistance, temperature} curve at the Curie point, first detected by Svensson in nickel, has been verified, and a similar kink has been found in iron. Detailed graphs for the Curie-point regions are given in figure 3*a* for nickel and in figure 5 for iron. The curves for the various specimens of nickel were almost identical. The data given are for a Hilger specimen and show a kink at 629·3° K. and a value 4·627 of R/R_0, where R_0 is the resistance at 0° C. A second Hilger specimen gave a kink at 629·8° K., with R/R_0 equal to 4·603.

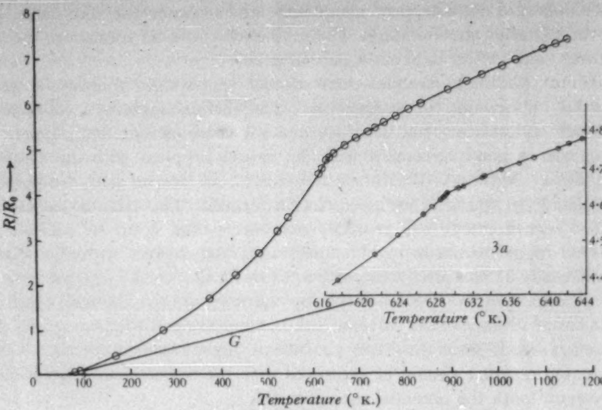

Figure 3. Resistance of nickel as a function of temperature.

Figure 3*a*. The neighbourhood of the Curie point.

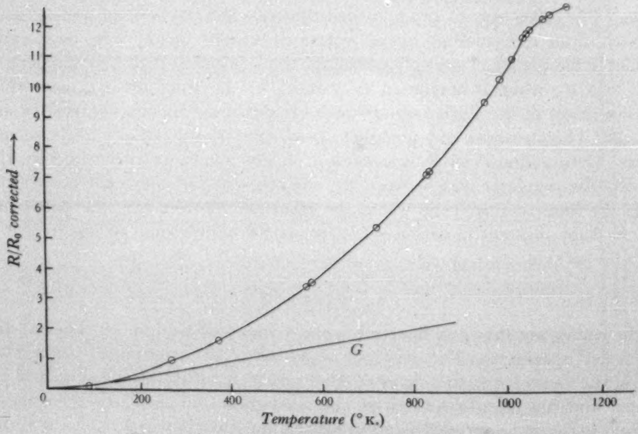

Figure 4. Resistance of iron as a function of temperature.

The specimen of nickel from the International Nickel Co. had corresponding values of 629·6° K. and 4·605. In iron the kink was found at 1039° K. with R/R_0 equal to 11·67.

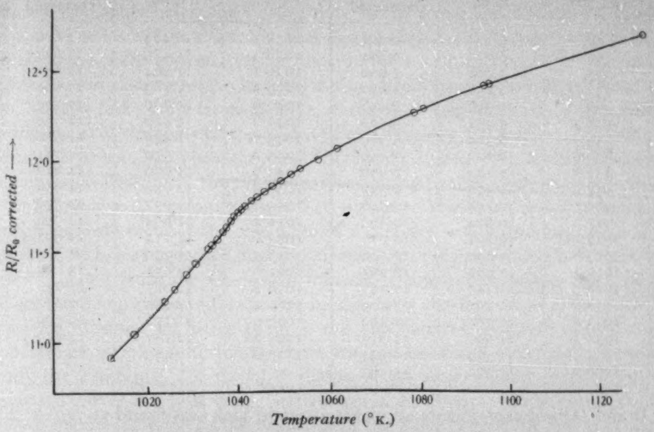

Figure 5. Resistance of iron as a function of temperature.

Table 1. Resistance of nickel as a function of temperature

T (° K.)	R/R_0	T (° K.)	R/R_0	T (° K.)	R/R_0
77	0·090	629·2	4·622	740·1	5·384
90	0·125	629·4	4·627	760·0	5·493
169	0·440	630·5	4·641	785·8	5·626
273	1·000	631·1	4·645	815·3	5·775
373	1·681	633·2	4·669	839·5	5·898
435	2·196	633·4	4·673	898·6	6·178
483·5	2·679	635·2	4·690	939·7	6·366
526	3·149	637·1	4·706	972·6	6·513
551·5	3·450	638·7	4·723	1016·0	6·703
617·5	4·392	641·1	4·746	1044·0	6·825
621·5	4·461	642·3	4·759	1102·0	7·064
624	4·513	643·8	4·774	1128·2	7·171
626·9	4·570	651·8	4·838	1143·1	7·228
627·8	4·590	675·3	5·005	1153·1	7·265
628·6	4·608	701·2	5·166		
628·9	4·615	724·8	5·302		

In table 2 a third column showing R/R_0 corrected has been added. The work of Meissner and Voigt(5) has indicated that iron of a quite high degree of purity may have a very marked residual resistance. The resistance of the iron specimen was therefore measured in liquid hydrogen, which led to an estimate of 0·020 R_0 for the residual resistance. Assuming then that this amount should be subtracted from the resistance at any other temperature, we have

$$R/R_0 \text{ corrected} = (R/R_0 - 0{\cdot}02)/0{\cdot}98.$$

Table 2. Resistance of iron as a function of temperature

T (°K.)	R/R_0	R/R_0 corrected	T (°K.)	R/R_0	R/R_0 corrected
20	0·021	0·001	1037·1	11·404	11·612
90	0·122	0·104	1038·3	11·439	11·647
273	1·000	1·000	1039·1	11·464	11·673
373	1·638	1·650	1039·9	11·483	11·692
566	3·398	3·446	1040·6	11·499	11·709
578·3	3·531	3·581	1041·6	11·520	11·730
719·5	5·300	5·386	1043·0	11·549	11·760
830·6	7·026	7·146	1044·2	11·570	11·781
837·8	7·144	7·266	1045·9	11·600	11·812
955·9	9·378	9·545	1047·5	11·624	11·836
989·1	10·124	10·306	1049·2	11·657	11·870
1012·2	10·670	10·863	1051·4	11·693	11·906
1017·25	10·821	11·017	1053·6	11·723	11·937
1023·8	11·000	11·200	1057·5	11·770	11·985
1026·1	11·062	11·263	1061·6	11·831	12·047
1028·9	11·145	11·347	1078·4	12·027	12·247
1031·0	11·205	11·409	1080·4	12·050	12·271
1033·4	11·287	11·492	1093·9	12·176	12·399
1034·3	11·307	11·513	1095·2	12·187	12·410
1035·3	11·339	11·545	1129·6	12·449	12·678
1036·6	11·378	11·585			

In our earliest experiments on nickel a second kink was found at 740° K. This kink was much less well defined than the one at the Curie temperature, and was probably due to impurity, as it could not be verified after extremely careful examination of the very pure specimen from the International Nickel Co., or of specimens subsequently obtained from Messrs Hilger.

§ 4. DISCUSSION OF RESULTS

The explanation of the sharp kink at the Curie point has already been discussed elsewhere(6). Further discussion here seems unnecessary. From the Curie point up to the highest temperatures used, the curves for both nickel and iron are markedly concave to the temperature axis. This fact presumably invalidates Gerlach's extrapolation and consequently his formal theory concerning the connexion between resistance and energy of spontaneous magnetization.

An entirely different explanation of the resistance of ferromagnetics and other transition metals has been given by Mott(7, 8, 9). Palladium, a paramagnetic transition metal in the same column of the periodic table as nickel, has 0·6 electron per atom in the 5*s* shell and consequently a similar number of positive holes in the 4*d* shell. The energies of the two bands overlap, but the density of the states at the surface of the Fermi distribution is much greater in the 4*d* band than in the 5*s* band. Consequently during scattering processes $s \rightarrow d$ transitions will be more probable than $s \rightarrow s$ transitions. This gives rise to the abnormally high resistance which is characteristic of the transition metals. The theory has been successful in explaining the concavity of the palladium {resistance, temperature} curve towards the temperature axis and various facts concerning the resistance of palladium-gold alloys(10).

Above its Curie point nickel will be expected to behave like palladium and therefore to give a curve concave to the temperature axis.

If the transition metal happens also to be ferromagnetic, then other considerations will also apply below the Curie point. In the ferromagnetic state the spins of the positive holes will be aligned so that in accordance with the exclusion principle only electrons of the correct spin can undergo the $s \rightarrow d$ transition. Thus one-half of the conduction electrons (i.e. electrons in the s band) have a much larger mean free path, actually four or five times as large, as the other half. With rise of temperature the alignment of the spins of the positive holes becomes less perfect, and scattering of electrons of both spins into the d band becomes possible. Thus as the spontaneous magnetization disappears the resistance rises owing to this additional scattering.

In figures 3 and 4 a line (marked G in both cases) has been drawn representing a rough estimate of what the resistance of nickel and iron would have been if the ferromagnetism had remained unchanged with rise of temperature. These lines have been calculated from the Gruneisen formula, characteristic temperatures of 375 and 420° K. being assumed for the two metals. The absolute values of the ordinates have been obtained by fitting them to the experimental resistance curves at low temperatures where the ferromagnetism has not decreased sufficiently to modify greatly the resistance. The rapid deviation of the experimental curves from the Gruneisen curves is very striking, particularly as the fitting at low temperatures will assign a maximum value to the ordinates of the latter curves. In iron at 0° C., for instance, R/R_G, where R_G is the Gruneisen resistance, is of the order 1·6, whereas the decrease in the spontaneous magnetization from the value at absolute zero is something under 2 per cent. This seems incompatible with any theory which ascribes the resistance-change to a change in the magnetic energy. It is, however, in striking agreement with the Mott theory in which the probability of scattering into the d band is proportional to

$$\left\{1-\frac{\sigma}{\sigma_0}\right\}^{\frac{1}{3}},$$

where σ_0 is the spontaneous magnetization at the absolute zero of temperature and σ is its value at any other temperature.

According to Mott⁽⁹⁾ the conductivity of the half of the electrons with spins in the direction of magnetization is proportional to

$$\frac{1}{(1-\sigma/\sigma_0)^{\frac{1}{3}}+\frac{1}{4}},$$

so that if $1-\sigma/\sigma_0=0{\cdot}01$, the cube root is 0·21, and the contribution from these electrons to the conductivity is about halved. The effect of change of magnetization on the resistance may thus be quite large at low temperatures.

§ 5. ACKNOWLEDGEMENTS

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REFERENCES

(1) Gerlach and Schneiderhahn. *Ann. Phys., Lpz.*, **5**, vi, 772 (1930).
(2) Potter. *Proc. roy. Soc.* A, **132**, 560 (1931); *Phil. Mag.* **13**, 233 (1932).
(3) Svensson. *Ann. Phys., Lpz.*, **5**, xxii, 97 (1935).
(4) Cooke and Swallow. *J. sci. Instrum.* **6**, 287 (1929).
(5) Meissner and Voigt. *Ann. Phys., Lpz.*, **5**, vii, 761 and 892 (1930).
(6) Mott. *Proc. phys. Soc.* **47**, 571 (1935).
(7) Mott. *Proc. roy. Soc.* A, **153**, 699 (1936).
(8) Mott. *Proc. roy. Soc.* A, **156**, 368 (1936).
(9) Mott and Potter. *Nature, Lond.*, **139**, 411 (1937).
(10) Conybeare. *Proc. phys. Soc.* **49**, 29 (1937).

ABSTRACT SPECTRA AND PHOTODISSOCIATION OF HALIDES AND OXYHALIDES OF SULPHUR, SELENIUM AND TELLURIUM

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ABSTRACT. The absorption spectra of $SOBr_2$, $S_2O_5CL_2$, $SeCl_4$, $SeOCl_2$, Se_2Cl_2, $SeBr_4$, Se_2Br_2, $TeCl_2$, $TeCl_4$, $TeBr_2$ and $TeBr_4$ in the vapour state are investigated, and the photodissociation processes and bond energies are determined. The results confirm those previously obtained for the chlorides and oxychlorides of sulphur.

§ 1. INTRODUCTION

RECENTLY some investigations of the continuous absorption spectra of polyatomic inorganic molecules have been undertaken in order to extend the spectroscopic basis of the theory of valency(1). Such investigations are interesting because the correlation of the beginnings of regions of selective absorption in the vapour state to photodissociation processes permit us to determine the single-bond energies directly, and not as part of a grand total, as in thermochemical observations. In these experiments it has been found that the bond energies are additive in the same inorganic molecule and remain constant in different molecules, so long as the central atom is in a minor and not in its maximal state of valency. In the latter case the energy conditions are entirely changed, and this has been connected with the fact that maximal valency always means the activation of the group of s^2 electrons, whose repulsive character is now well established by new band-spectroscopic evidence concerning diatomic halides of the second and fourth groups and oxides of the second and third groups of the periodic table(2). Particularly striking examples of the additivity and constancy of the bond energies have been found among the chlorides and oxychlorides of sulphur, and the object of the present paper is to extend these investigations to similar molecules. We have measured the absorption spectra and determined the photodissociation processes and bond energies of the following molecules in the vapour state: $SOBr_2$, $S_2O_5Cl_2$, $SeCl_4$, $SeOCl_2$, Se_2Cl_2, $SeBr_4$, Se_2Br_2, $TeCl_2$, $TeCl_4$, $TeBr_2$, $TeBr_4$. The experimental results entirely confirm those obtained earlier, and cannot be understood otherwise than in a pair-bond theory of valency, in which each linkage is produced by a pair of electrons, one from each atom, and localized between the atoms.

§ 2. THERMOCHEMICAL CALCULATIONS

In the previous papers, since the thermochemical data are more or less known, we were able to calculate, for the derivatives of sulphur, the heat of dissociation into the gaseous atoms directly and individually in the usual way by means of Born's cycle. For derivatives of selenium and tellurium, however, the thermochemical data are much less known, the heat of formation from the elements is unknown for some of the compounds, and their heats of sublimation are entirely missing. We shall therefore follow a slightly different course here, and first calculate the most probable values for the various bond energies and then compare them with the experimental results obtained from the absorption spectra.

As the basic values of the energy of dissociation of S_2, Se_2 and Te_2 into unexcited atoms we use the values of 88, 59 and 44 kcal./mol. obtained, as in the earlier papers, from the direct observations of the convergence point(3) of the band spectrum by deducting the excitation energy of the ^1D term of the corresponding atom. This procedure involves the assumption that the ground state of each of the three molecules is $^3\Sigma$, because in the case of a $^1\Sigma$ state the excitation energy of ^1D would have to be deducted twice. For S_2 the triplet character is established by the rotational analysis of Christy and Naudé(4) and the above value from the convergence point appears to be the most accurate one. Olsson's rotational analysis(5) of some bands of the Se_2 spectrum might suggest that those bands are due to transitions between singlet levels, but it is not yet clear whether this interpretation is correct and whether the bands involve the ground state at all. Lessheim and Khanna* have found selenium vapour to be paramagnetic—a result which definitely supports this view. These points will be discussed at greater length in forthcoming papers from this laboratory; here it might be sufficient to point out that the above dissociation energies, as will be seen, agree perfectly well with the values obtained from the photodissociation of the halides and oxyhalides, which, in conjunction with the thermochemical data, are an independent means of obtaining the dissociation energies of the ground states of the diatomic molecules. Furthermore the triplet character of the ground states of Se_2 and Te_2 is corroborated by the fact that the assumption of a $^1\Sigma$ state would lead to dissociation energies of 35 and 14 kcal./mol., respectively, which appear too low as compared with the values obtained by the extrapolation of the vibrational levels, and also as compared with the values which have been estimated by means of the law of mass action from observations of the vapour pressure(6). To the values, 88, 59 and 44 kcal./mol., of the dissociation energy of the molecules S_2, Se_2 and Te_2, respectively, the heat of sublimation (S) has to be added in order to obtain the total energy necessary to transform the solid elements into gaseous atoms. Furthermore, for sulphur and selenium the heat of polymerization (P) has to be added too, while the vapour of tellurium consists of diatomic molecules. The values† used here are (in kcal./g.-atom):

$$S\,(\mathrm{S})+P\,(\mathrm{S})=15, \quad S\,(\mathrm{Se})+P\,(\mathrm{Se})=17{\cdot}5, \quad S\,(\mathrm{Te})=31.$$

The energy to convert 1 g.-atom of the solid elements into gaseous atoms comes therefore to 59, 47 and 53 kcal. for sulphur, selenium, and tellurium respectively. The increase for tellurium is remarkable and will be discussed below. For bromine we obtain 25 kcal. in a similar way, while for oxygen and chlorine the dissociation energy of the diatomic molecule is directly known.

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* Private communication from Dr H. Lessheim.

† These figures are taken mostly from Mellor's *Treatise*, a few from Landolt-Boernstein's *Tables*.

The atomic energy of dissociation (*D*) of a molecule into its constituent atoms is obtained by means of Born's cycle by adding to the above values the thermochemical heat of formation from the elements (*Q*) and deducting the heat of sublimation (*S*) of the compound itself. The latter are not known at all, and are estimated here mostly from the boiling-points by means of Forcrand's formula, as discussed in earlier publications. They represent small amounts of energy as compared with *D* or *Q*, and the error cannot seriously influence the final result.

Table 1

MX_n	Q	S	D	$D(M_2)$	$D_B(M-X)$
S_2Br_2	2	10	162	S═S 88	S—Br = 37
$SeCl_2$	−11	(~5)	88		$\frac{1}{2}D$ = Se—Cl = 44
$SeCl_4$	36	~14	188		$\frac{1}{4}D$ = Se—Cl = 46
Se_2Cl_2	22	~12	162	Se═Se 59	Se—Cl = 51
$TeCl_4$	77	24	226		$\frac{1}{4}D$ = Te—Cl = 56·5
$TeBr_4$	57	~21	193		$\frac{1}{4}D$ = Te—Br = 48

The first four columns of table 1 give the results of the final calculations for those halides of selenium and tellurium where *Q* is known, and for thionyl bromide. If the bond energies (D_B) are rigorously additive, the division of the atomic heats of formation given in columns 5 and 6 obtains. For the Se—Cl bond three figures are available, which are quite close to each other, in spite of the error brought about by the estimated heats of sublimation and in spite of the fact that the additivity of the bond energies holds only approximately on account of the varying repulsive forces between the atoms. For the S—Cl bond the corresponding figures have been calculated in earlier publications, the values obtained from $SOCl_2$, S_2Cl and SCl_2 being 48, 46 and 60 kcal./mol. respectively. Taking, as far as possible, the weighted mean of several values, we obtain the following figures for the bond energies in molecules formed by divalent and tetravalent atoms of the sixth group:

Table 2

	S	Se	Te
Cl	50	47	55
Br	37	(~42)	48

For the Se—Br bond no figures are available at all and the value of 42 kcal./mol. is estimated from the S—Br and Te—Br bond according to the corresponding energy differences in the series of the chlorides. It is remarkable that the energies of the Te—Cl and Te—Br bond are higher than those of the corresponding bonds of S and Se, while generally the bond energies decrease in the same group of the periodic system with increasing atomic number. This exception, however, appears to be quite genuine. It already finds expression in the corresponding values of *S* (Te) and *Q*; and Roth and Becher(7) have observed a similar phenomenon for the trioxides of these elements. The values for the Te—Cl and the Te—Br bond agree approximately with those calculated by Larionov(8). The anomalous course of the bond energies in this group is doubtless connected with the fact that the energies of excitation, and probably also those of ionization, increase again from Se to Te instead of decreasing.

Although the above figures do not claim great accuracy, they are sufficient to make possible a comparison with the photolytic dissociation energies. As remarked above, the photodissociation, as measured by the long-wave limit of a region of continuous absorption, investigates directly the dissociation energy of a single bond, as distinct from thermochemical measurement, where mainly the energy due to the grand total of several bonds is observed. If therefore the long-wave limits agree with the above values and with those of the S═S, Se═Se, S═O, and Se═O bonds known from the band spectra of the diatomic molecules, this will be a confirmation of the earlier experiments, and will show that in these molecules also the bond energies behave approximately additively in the same molecule and are constant in different molecules.

§ 3. REMARKS ON THE EXPERIMENTAL RESULTS

The absorption spectra were taken with the apparatus described earlier(1), and the long-wave limits and the maxima of the various regions of selective absorption were determined by means of a recording microphotometer. Figures 1 to 3 are samples of these photometer records. As discussed elsewhere, the long-wave limits of such maxima are not easy to measure with accuracy, because, if the vapour pressure is too low, only those wave-lengths are absorbed for which the absorption coefficient already has appreciably high values, and consequently the energy-values obtained are too high. If, on the other hand, the vapour pressure is increased too much, the absorption obtained does not belong to the lowest vibrational level of the molecule, because the number of molecules in higher vibrational levels increases with the vapour pressure (and temperature), and the absorption spectrum yields too low values of the energy of dissociation. These difficulties are unavoidable because the continuous absorption measures transitions between stable and unstable states and the energies obtained are, in reality, energies of excitation not of dissociation. They can be minimized to some extent by taking the absorption spectrum over a long range of varying pressures, and a comparison of different spectrograms of the same substance makes it easier to determine that long-wave limit belonging to the molecule in its lowest state of vibration. Because most of the compounds investigated here have rather low saturation pressures, and because most of them are inclined to decompose on heating,* not so many spectra could be obtained as, for instance, in the case of chlorides and oxychlorides of sulphur, and the following figures cannot

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* The experiments recorded here were carried out in the spring of 1936, and the result was published in a preliminary note(9). To ascertain that the absorption maxima are due to these compounds and that no decomposition occurs on heating, the absorption spectra of those for which a suitable solvent could be found have been measured in solution(10). The same regions of selective absorption have been found in solution as in the vapour state.

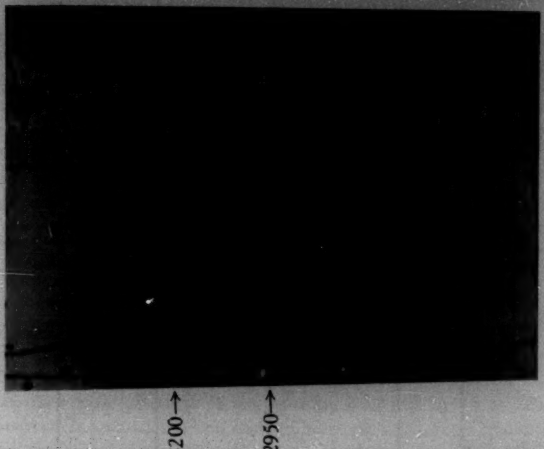

Figure 1. Photometer record of Se_2Cl_2 absorption. Lower curve, source of light; upper curve, Se_2Cl_2 vapour in 5-cm. absorption tube at 1 mm. vapour pressure.

Figure 2.

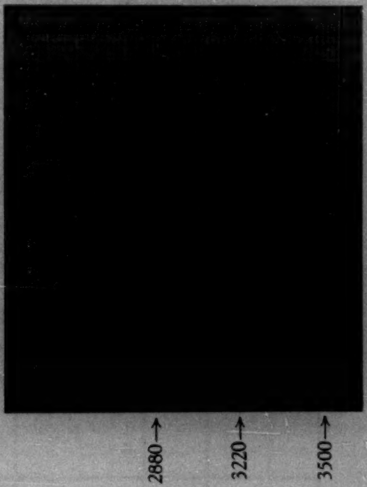

Figure 3.

Figure 2. The same, at longer wave-length. Lowest curve, source of light; second curve, 1 mm. vapour pressure; third curve, 3 mm. vapour pressure. Development of maximum at λ3500 A.

Figure 3. Photometer record of Se_2Br_2 absorption, main maximum at λ3220 A. Lower curve, source of light; upper curve, Se_2Br_2 vapour in 10-cm. absorption tube at 75° C.

Table 3

	First absorption				Second absorption				Third absorption				Fourth absorption			
	Long-wave lim.		Maximum		Long-wave lim.		Maximum		Long-wave lim.		Maximum		Long-wave lim.		Maximum	
	λ (mμ.)	kcal./mol.	λ (mμ.)	Volts	λ (mμ.)	kcal./mol.	λ (mμ.)	Volts	λ (mμ.)	kcal./mol.	λ (mμ.)	Volts	λ (mμ.)	kcal./mol.	λ (mμ.)	Volts
$SOBr_2$					378	75	327	3·7	281	101	265	4·6	245	116		
					$2D_B(S—Br)=74$				$2D_B(S—Br^*)=95$				$D(S=O)=116$			
$SeCl_4$	(415)	(68)	325	3·8					301	94	275	4·5	(250)	(114)	(240)	(5·1)
$SeOCl_2$									315	90	266	4·6	250	114		
Se_2Cl_2					410	69	350	3·5	320	89	295	4·2	249	114	(237)	(5·2)
	$D_B(Se—Cl)=47$				$D(Se_2)=59$				$2D_B(Se—Cl)=94$							
$SeBr_4$	580	47	490	2·5	530	55	427	2·9	350	81	262	4·7	250	114		
Se_2Br_2					465	61	384	3·2	350	81	322	3·8	288	98	257	4·8
	$D_B(Se—Br)\sim 42$				$D_B(Se—Br^*)\sim 53$ $D(Se_2)=59$				$2D_B(Se—Br)\sim 84$				$2D_B(Se—Br^*)\sim 106$ $D(Se=Se^*)=87$			
$TeCl_2$	480	59	317	3·9					290	98	251	4·9	246	115		
$TeCl_4$	480	59	324	3·8					272	105	247	5·0				
	$D_B(Te—Cl)=55$								$2D_B(Te—Cl)=110$							
$TeBr_2$	535	53	473	2·6	420	67	380	3·2	340	84	314	3·9	293	97	(228)	5·4
$TeBr_4$	525	54	465	2·7			(400?)		296	96	265	4·6	(249)	(114)		
	$D_B(Te—Br)=48$				$D_B(Te—Br^*)=59$				$2D_B(Te—Br)=96$				$2D_B(Te^*—Br)=124$ $2D_B(Te—Br^*)=108$			

claim the same degree of accuracy. It is also possible that maxima which would be stronger with increased vapour pressure of the undecomposed compound have not been found. The figures of the absorption maxima and their long-wave limits are collected in table 3, where the energy values of the photodissociation processes also are given for comparison. D_B denotes bond energies obtained from thermochemical data, D denotes dissociation energies taken from band spectra of diatomic molecules, and dissociation processes involving an excited product are marked by an asterisk against the atom which dissociates in an excited state.

§4. EXPERIMENTAL RESULTS FOR THIONYL BROMIDE AND PYROSULPHURYL CHLORIDE

Thionyl bromide possesses three regions of selective absorption with long-wave limits at 378, 281 and 245 mμ. respectively. The maxima corresponding to the first and second are at 327 and 265 mμ.; that belonging to the third region could not be found. The first long-wave limit extends more and more towards the visible spectrum with increasing vapour pressure or temperature. The first figure 378 mμ. belongs to a spectrum taken in a 10-cm. cell with 0·5 mm. pressure. With pressures of some millimetres the beginning of absorption can be shifted into the violet region, to about 425 mμ.; this explains why $SOBr_2$ in the liquid state possesses a brownish red colour. The energy difference between long-wave limit and maximum is small and about the same for the two first maxima, i.e. about 4000 and 5000 cm.$^{-1}$ respectively. This indicates that the two repulsive curves are rather flat and run nearly parallel, and that the second maximum represents a dissociation into excited products. Indeed, the obvious correlation of the photodissociation processes agrees very well with this view. Expressed in kcal./mol., the values of the three long-wave limits are $h\nu_1 = 75$, $h\nu_2 = 101$, $h\nu_3 = 116$ respectively. The first figure agrees very well with twice the bond energy of the S—Br bond, i.e. 74, and the third one is exactly equal to the dissociation energy of SO, as known from the band spectrum. The electronic separation of the ground state of the Br atom is 3685 cm.$^{-1}$ or about 10·5 kcal./mol. If twice this amount is added to the value of 74 kcal./mol., we obtain 95 kcal./mol., in fairly good agreement with the value of the second long-wave limit. The three regions of selective absorption therefore represent the following dissociation processes:

$$SOBr_2 + h\nu_1 = SO + 2Br(^2P_{\frac{3}{2}}),$$
$$SOBr_2 + h\nu_2 = SO + 2Br(^2P_{\frac{1}{2}}),$$
$$SOBr_2 + h\nu_3 = SBr_2 + O(^3P).$$

This is exactly the behaviour to be expected from our knowledge of $SOCl_2$. Also, the first photodissociation of thionyl chloride is due to the splitting off of both the chlorine atoms together. The only difference is that the doublet separation of Cl is 881 cm.$^{-1}$ or 2 kcal./mol. only, and maxima due to a dissociation involving two excited chlorine atoms merge with those due to unexcited atoms and cannot be separated from them. The molecules $SOCl_2$ and S_2Cl_2 possess a first maximum of selective absorption at about 250 mμ. with a long-wave limit at about 280 mμ., corresponding to the energy of two S—Cl bonds. A similar maximum appeared in SCl_2 as the second one. The fact that the first maximum of $SOBr_2$ shifts to a longer wave-length by an amount of almost 10000 cm.$^{-1}$, to the position corresponding to the breaking up of two S—Br bonds, makes it perfectly certain that the above correlation and the earlier one for the chlorides and the oxychloride are correct. The energy of the S—Br bond was calculated from sulphur monobromide S_2Br_2 because the heat of formation of $SOBr_2$ is not known. That of the S=O bond was taken directly from the band spectrum of SO. The good agreement of these figures with those of the long-wave limits of the absorption spectrum of $SOBr_2$ thus confirms at once that the bond energies remain nearly unaltered in all the derivatives of divalent and tetravalent sulphur.

Pyrosulphuryl chloride, $S_2O_5Cl_2$, possesses a continuous end-absorption only, whose long-wave limit in a 10-cm. cell at about 2 mm. vapour pressure lies at 246 mμ. at room temperature, and at 251 mμ. (113 kcal./mol.) at slightly increased temperature (40° C.). The absorption appears to be very similar to that of SO_2Cl_2, and it is therefore probable that the same photolytic process, i.e. the separation of an unexcited O atom, takes place here also.

§ 5. EXPERIMENTAL RESULTS FOR HALIDES AND OXYHALIDES OF SELENIUM

Selenium tetrachloride possesses a main maximum of selective absorption at 275 mμ. with a long-wave limit at 301 mμ. (94 kcal./mol.). On the long-wave side there appears a second maximum at about 325 mμ. which develops better at higher temperatures, and whose long-wave limit we followed up to 415 mμ. (68 kcal./mol.); but this energy value is certainly considerably too high. We could not raise the temperature above 80 to 100° C., because dissociation occurs at atmospheric pressure at 200° C. and is complete at about 290° C. (cf. Mellor's *Treatise*). Also, on the short-wave side a further region of selective absorption appears, but here again we could not obtain very accurate determinations on account of the facile decomposition of this substance. It appears, however, to lie somewhere in the neighbourhood of 240 mμ. and to have its long-wave limit near 250 mμ.

Selenium oxychloride possesses two regions of selective absorption. The first maximum lies at 266 mμ., but the second maximum could not be measured; the two long-wave limits are at about 315 mμ. (90 kcal./mol.) and 250 mμ. (114 kcal./mol.) respectively.

Selenium monochloride Se_2Cl_2 exhibits three regions of selective absorption with maxima at 350, 295 and about 237 mμ. respectively, and long-wave limits at 410, 320 and 249 mμ. respectively, the corresponding values in kcal./mol. being 69, 89 and 114 respectively.

From these figures it can be seen that all three compounds possess a similar maximum of selective absorption at about 270 mμ. The energy values of the three long-wave limits, i.e. 94, 90 and 89 kcal./mol., agree very well with the not very accurate value of 94 kcal./mol., obtained from thermochemical data for the splitting of two Se—Cl bonds. The same phenomenon was shown by the corresponding sulphur compounds and it will be seen later that the tellurium chlorides behave in the same way. Always, the most pronounced maximum of absorption of the chlorides and oxychlorides and the bromides and oxybromides of divalent and tetravalent S, Se and Te possesses a long-wave limit in very good agreement with the thermochemical value of the adiabatic dissociation of *two* halogen atoms. We therefore correlate this region of selective absorption to the photodissociation processes $SeCl_4 \rightarrow SeCl_2 + 2Cl$, $SeOCl_2 \rightarrow SeO + 2Cl$ and $Se_2Cl_2 \rightarrow Se_2 + 2Cl$.

While in the corresponding molecules $SOCl_2$, S_2Cl_2 and $SOBr_2$ this maximum was that with the lowest energy value and no photodissociation due to the separation of a single halogen atom occurs with appreciable probability, Se_2Cl_2 exhibits a new maximum at longer wave-length than the above maximum. Se_2Cl_2, however, is also the first molecule in this series which possesses another linkage with a bond energy lower than that of the two halogen bonds together, i.e. the Se=Se bond. Indeed the observed 69 kcal./mol. is in fairly good agreement with the 59 kcal./mol. taken from the convergence point of the band spectrum of Se_2, and since we find a similar maximum in Se_2Br_2, there is little doubt about the correlation of its long-wave limit to the dissociation process $Se_2Cl_2 \rightarrow SeCl_2 + Se$.

The short-wave maxima will belong to photolytic processes involving excited dissociation products, and for $SeOCl_2$ the process $SeOCl_2 \rightarrow SeCl_2 + O$ also has to be considered, the dissociation energy of SeO being about 97 kcal./mol. according to its band spectrum(11). The data are, however, not accurate enough definitely to decide this question.

There remains still the first maximum of $SeCl_4$. Its long-wave limit at 68 kcal./mol. is rather high compared with the energy of 47 kcal./mol. calculated for the Se—Cl bond. But in $SeBr_4$ we find a similar region of selective absorption, which doubtless corresponds to the breaking up of a single Se—Br bond; and, again, the same occurs in $TeCl_4$ and $TeBr_4$. Knowing that the energy value of this maximum must be too high, because it was very weakly developed on the original plates, and the true beginning of absorption of the vibrationless molecule was not reached, we correlate the first absorption region of selenium tetrachloride to the process $SeCl_4 \rightarrow SeCl_3 + Cl$. But it should be clearly understood that this correlation is based mainly on the analogy with the tetrahalides discussed below.

Denoting the energy of the long-wave limits at 415 mμ. (or, probably, longer waves) by $h\nu_1$, at 410 mμ. by $h\nu_2$, and at 301, 315 and 320 mμ. respectively by $h\nu_3$, we obtain the following equations for the photodissociation processes:

$$SeCl_4 + h\nu_1 = SeCl_3 + Cl; \quad Se_2Cl_2 + h\nu_2 = SeCl_2 + Se;$$

$$SeCl_4 + h\nu_3 = SeCl_2 + 2Cl; \quad Se_2Cl_2 + h\nu_3 = Se_2 + 2Cl; \quad SeOCl_2 + h\nu_3 = SeO + 2Cl.$$

Selenium monobromide, Se_2Br_2, and *selenium tetrabromide*, $SeBr_4$, behave exactly similarly. Both possess a very pronounced maximum of selective absorption with a long-wave limit at 350 mμ. (81 kcal./mol.). This is again in very good agreement with 84 kcal./mol. the energy estimated for two Se—Br bonds. It is interesting to note that the maxima themselves are different, namely at 322 mμ. and 262 mμ. respectively, although the long-wave limits are identical. It appears, however, to be premature to discuss such differences concerning the probabilities of transition by means of a poly-dimensional Franck-Condon diagram.

A maximum, which could be correlated to the separation of a single Br atom according to the bond energy of 42 kcal./mol. of the Se—Br linkage, is missing in Se_2Br_2, but is very clearly exhibited in $SeBr_4$ at 490 mμ., with a long-wave limit at 550 mμ. (47 kcal./mol.). This maximum is already well developed at about 70° c., and the reddish brown colour of the substance indicates that it is due to the non-decomposed compound. It is the first clear evidence that the tetrahalides behave differently from the mono- and oxyhalides but similarly to the dihalides in as much as the photolytic process due to the separation of a single halogen atom occurs with them.

Between this and the main maximum, $SeBr_4$ exhibits another one at 427 mμ., whose long-wave limit lies at 530 mμ. (55 kcal./mol.). The energy difference between this maximum and the first one is 0·4 v., in very good agreement with the doublet separation of the ground state of Br, namely 3685 cm^{-1} or 0·45 v. Also the main maximum is accompanied by one of shorter wave-length, for which the maximum itself could not be determined, but whose long-wave limit lies at 250 mμ. The energy difference from the corresponding value of the main maximum is 0·6 v.; and, because the differences between the long-wave limits are always less reliable than those of the maxima themselves, we believe that it will correspond to the dissociation of two excited Br atoms rather than to a process involving an excited polyatomic radical. Denoting by $h\nu_1$ to $h\nu_4$ the energy values corresponding to the four long-wave limits of $SeBr_4$ at 580, 530, 350 and 250 mμ. respectively, we correlate the photolytic processes to them as follows, that of the last one not being quite certain:

$$\begin{aligned}
SeBr_4 + h\nu_1 &= SeBr_3 + Br(^2P_{\frac{3}{2}}),\\
SeBr_4 + h\nu_2 &= SeBr_3 + Br^*(^2P_{\frac{1}{2}}),\\
SeBr_4 + h\nu_3 &= SeBr_2 + 2Br(^2P_{\frac{3}{2}}),\\
SeBr_4 + h\nu_4 &= SeBr_2 + 2Br^*(^2P_{\frac{1}{2}}).
\end{aligned}$$

Se_2Br_2 also possesses two more maxima besides the main maximum. That on the long-wave side lies at 384 mμ. with a long-wave limit at 465 mμ. (61 kcal./mol.). This latter value is slightly higher than that of the second maximum of $SeBr_4$ and agrees better with the dissociation energy of Se_2, namely 59 kcal./mol. It also cannot be correlated to an excited Br atom as a dissociation product, because a single Se—Br bond is not fissured at longer wave-lengths, such a region of selective absorption being entirely missing. A third region of selective absorption occurs, which has a long-wave limit at 288 mμ. and a maximum at 257 mμ. The energy difference between the second and third maxima is 1·0 v., in good agreement with the excitation energy of two Br atoms (0·9 v.). If the three long-wave limits in order of increasing energy be again denoted by $h\nu_1$, $h\nu_2$ and $h\nu_3$, their obvious correlation to photodissociation processes is:

$$\begin{aligned}
Se_2Br_2 + h\nu_1 &= SeBr_2 + Se(^3P),\\
Se_2Br_2 + h\nu_2 &= Se_2 + 2Br(^2P_{\frac{3}{2}}),\\
Se_2Br_2 + h\nu_3 &= Se_2 + 2Br^*(^2P_{\frac{1}{2}}).
\end{aligned}$$

§ 6. EXPERIMENTAL RESULTS FOR CHLORIDES AND BROMIDES OF TELLURIUM

Tellurium tetrachloride and *tellurium dichloride* possess continuous absorption spectra which are surprisingly similar. In the solid state the two substances are quite differently coloured, $TeCl_4$ being white, and $TeCl_2$ black, and green if powdered. At first, therefore, we believed that one of the two absorption spectra would be due to the decomposition of one of these compounds; but from measurements of the vapour pressure (cf. Mellor's *Treatise*) it appears to be certain that both these molecules do not decompose till about 400° C., whereas the spectra are already well developed at temperatures of about 250 and 190° respectively, which are near the melting-points ($TeCl_4$ 224°, $TeCl_2$ 175°). Indeed, both these compounds are known to give yellow vapours in spite of their different colours in the crystalline state, and these are probably due to a deformation (in the Fajana sense) and disappear for the isolated gaseous molecules. Slight differences in the colour of the vapour occur, because the value of the absorption coefficient is different in the visible region. Another reason is that the vapour of $TeCl_2$ exhibits a band spectrum in addition to its continuous absorption, which lies between 5570 and 5010 A. These bands, and also similar ones for $TeBr_2$ and $SeCl_2$, have been recorded in the meantime by other authors and correlated to these triatomic molecules(8). We have observed these systems in $TeCl_2$ and $TeBr_2$, and some preliminary observations of Larionov on some of the maxima of selective absorption of these compounds agree very well with the figures obtained by us. Both molecules, $TeCl_2$ and $TeCl_4$, exhibit again a pronounced maximum of selective absorption in the ultra-violet and a slightly weaker one extending towards the visible spectrum. The former maximum was found at 251 mμ. in $TeCl_2$ and at 247 mμ. in $TeCl_4$, the long-wave limits lying at 290 mμ. (98 kcal./mol.) and 272 mμ. (105 kcal./mol.) respectively. The latter maximum is at 317 mμ. for $TeCl_2$ and 324 mμ. for $TeCl_4$, the long-wave limit has been found at 480 mμ. (59 kcal./mol.) for both. The first long-wave limits of $TeCl_4$ and $TeBr_4$ have been measured by Sharma(12) at slightly different values. The exactly identical position of the beginnings of absorption is of course fortuitous, since the experimental conditions play such a great role just for the first long-wave limits, but there is no doubt that the two molecules possess essentially the same continuous absorption spectrum. For $TeCl_2$ a third absorption region with a limit at 246 mμ. (115 kcal./mol.) was found, indicating a dissociation involving excited radicals, or an excited Te atom in the ^1D state, for which the energy value, however, appears to be somewhat too low.

The energy value of the long-wave limits at 480 mμ. agrees very well with that of the Te—Cl bond calculated thermochemically as 55 kcal./mol.; those of the limits at 290 and 272 mμ. are only slightly smaller than double this figure. Denoting these energy values by $h\nu_1$ and $h\nu_2$ respectively, we obtain the following equations for the photolytic processes:

$$TeCl_2 + h\nu_1 = TeCl + Cl \text{ and } TeCl_4 + h\nu_1 = TeCl_3 + Cl,$$

$$TeCl_2 + h\nu_2 = Te + 2Cl \text{ and } TeCl_4 + h\nu_2 = TeCl_2 + 2Cl.$$

Both are in complete agreement with the results obtained in similar di- and tetrahalides of sulphur and selenium.

Again the continuous absorption spectra of *tellurium dibromide* and *tellurium tetrabromide* are almost exactly identical. They differ from those of the chlorides again in that they show a doubling of certain maxima, because a dissociation involving excited Br atoms is now possible, which cannot be found in chlorides on account of the extremely low excitation energy of the $^2P_{\frac{1}{2}}$ term of Cl.

As in the case of the chlorides, the vapours of these substances appear to be coloured differently from the crystals, slight differences between the colours of $TeBr_2$ and $TeBr_4$ in the gaseous state being due to the value of the absorption coefficient and the band spectrum of $TeBr_2$, observed also by us between about 7000 and 5500 A. The maxima of continuous absorption are developed clearly at temperatures of about 50° above the melting-points, where no decomposition appears to be possible.

Starting from the visible region, the first absorption maximum lies at 473 mμ. in $TeBr_2$ and at 465 mμ. in $TeBr_4$, the corresponding long-wave limits being at 535 mμ. (53 kcal./mol.) and 525 mμ. (54 kcal./mol.), in fair agreement with the 48 kcal./mol. calculated thermochemically for the Te—Br bond. In $TeBr_4$ a second maximum at about 400 mμ. is just indicated but could not be measured accurately; in $TeBr_2$, however, it appears more clearly at 380 mμ. with a probable beginning at 420 mμ. (67 kcal./mol.). The energy difference from the first maximum of $TeBr_2$ is 0·6 v., which agrees fairly well with the 0·45 v. of the doublet separation of $Br(^2P)$. In the ultra-violet again a pronounced main maximum is found at 314 mμ. for $TeBr_2$ and at 265 mμ. for $TeBr_4$; the long-wave limits are at 340 mμ. (84 kcal./mol.) and 296 mμ. (96 kcal./mol.) in good agreement with the thermochemical value of two Te—Br bonds, which comes to 96 kcal./mol. Still farther in the ultra-violet a fourth region of absorption is characterized by two wave limits at 293 mμ. (97 kcal./mol.) in $TeBr_2$ and 249 mμ (114 kcal./mol.) in $TeBr_4$. The corresponding photolytic processes may involve two excited Br atoms, or, in the case of $TeBr_2$, an excited Te atom. Adding the excitation energies to the thermochemical value of 96 kcal./mol. for the splitting of two Te—Br bonds, we obtain 124 kcal./mol. if a $Te(^1D)$ atom is involved and 108 kcal./mol. if two $Br(^2P_{\frac{1}{2}})$ atoms are involved. The agreement is not very good, but the dissociation of two excited Br atoms appears to be more probable. If the energy values of the first three maxima are denoted by $h\nu_1$, $h\nu_2$ and $h\nu_3$, the following correlation to photodissociation processes appears well established, which is also in agreement with the correlations for similar molecules formed by S and Se:

$$TeBr_2 + h\nu_1 = TeBr + Br(^2P_{\frac{3}{2}}) \text{ and } TeBr_4 + h\nu_1 = TeBr_3 + Br(^2P_{\frac{3}{2}}),$$

$$TeBr_2 + h\nu_2 = TeBr + Br(^2P_{\frac{1}{2}}),$$

$$TeBr_2 + h\nu_3 = Te + 2Br(^2P_{\frac{3}{2}}) \text{ and } TeBr_4 + h\nu_3 = TeBr_2 + 2Br(^2P_{\frac{3}{2}}).$$

§7. CONCLUSIONS

The results of the present investigations can be summarized as follows:

(1) The long-wave limits of the continuous absorption spectra of halides and oxyhalides formed by the atom of the sixth group of the periodic system agree entirely with the energies calculated for the various processes of photodissociation from thermochemical data.

(2) Considering the experimental difficulties in the accurate determination of long-wave limits of continuous absorptions and the uncertainty of the thermochemical figures, the agreement can be said to be satisfactory. This indicates a very flat potential curve of the upper repulsive levels which are the final terms of the absorption spectra. This may be connected with the fact that the diatomic molecules of this group possess two free valencies and exhibit as ground level a $^3\Sigma$ term. It appears plausible to assume that such a term produces strong van der Waals forces, on account of which the unstable terms of the polyatomic molecules will be less repulsive than in similar cases of other groups of the periodic system. The strong van der Waals forces are also shown by the great tendency of the diatomic elements to polymerize.

(3) Particular interest attaches to the fact that the region of selective absorption with lowest energy of the di- and tetrahalides uniformly corresponds to the dissociation of a single halogen atom, while in the mono- and oxyhalides such a photolytic process does not occur. As soon as the molecule possesses a double bond between two atoms of the sixth group, both the halogen atoms always dissociate simultaneously.

(4) The absorption spectra show directly the rupture of a single bond, not the grand total only as in many thermochemical observations. It is therefore established that the *bond energies*, at least in this class of molecules, are in the main *additive*, slightly modified rather than changed by the different forces of repulsion between the atoms of a molecule.

(5) Furthermore, the energy of one and the same bond remains practically constant in all possible combinations so long as the central atom is divalent or tetravalent. Only the transition to the hexavalent state changes the energetic conditions on account of the activation of the group of s^2 electrons, as discussed elsewhere at greater length.

The experimental facts mentioned under (4) and (5), i.e. the additivity of bond energies in the same molecule and their constancy in different molecules, can only be understood on the basis of strong localization of the bonds. The method of molecular orbitals can of course describe such strong localization by deep potential moulds. But it is at a loss to explain why it occurs, since the electrons act as bonding by themselves and the electron pairs are formed rather incidentally. In Heitler and London's pair-bond theory, however, the strong localization in molecules possessing a pronounced central atom is an outcome of the saturation of valencies, each of which is produced by a pair of electrons one from each atom and localized between them. The photodissociations of the halides and oxyhalides of the sixth group therefore indicate that the additional assumption of the method of molecular orbitals, by which it becomes a single-electron-bond theory of valency (i.e. the general identification of non-premoted with bonding electrons and of premoted with antibonding or non-bonding ones), is not correct, and that it is not permissible to neglect the wave-mechanical interaction of electrons being on the same orbital. While there is no doubt about the application of the method of molecular orbitals to the description of the undisturbed molecule, this result as to the dissociation (or formation) of the molecules is again in agreement with a great amount of experimental and theoretical evidence$^{(13)}$.

REFERENCES

(1) Asundi, R. K. and Samuel, R. *Proc. phys. Soc.* **48**, 28 (1936).
Khan, Mohd Jan and Samuel, R. *Proc. phys. Soc.* **48**, 626 (1936).
Parti, Y. P. and Samuel, R. *Proc. phys. Soc.* **49**, 568 (1937).
(2) Lessheim, H. and Samuel, R. *Phil. Mag.* **21**, 41, 1936 and earlier.
Asundi, R. K. and Samuel, R. *Proc. Indian Acad. Sci.* (*Bangalore*), **3**, 466 (1936), and a later paper in the Press.
(3) Rosen, B. *Z. Phys.* **43**, 69 (1927).
(4) Christy, A. and Naudé, S. M. *Phys. Rev.* **37**, 490, 903 (1931).
(5) Olsson, E. *Z. Phys.* **90**, 138 (1934).
(6) Wartenberg, H. v. *Z. anorg. Chem.* **56**, 332 (1908).
(7) Roth, W. A. and Becher, G. *Z. phys. Chem.* (A), **159**, 1 (1932).
(8) Wehrli, M. *Helv. phys. Acta*, **8**, 487 (1935); **9**, 329, 637 (1936).
Larionov, J. *Acta Physico-chimica, U.S.S.R.* **2**, 67; **3**, 11 (1935).
(9) Hussain, S. L. and Samuel, R. *Curr. Sci.* **4**, 734 (1936).
(10) Samuel, R. and Usman, M. *Proc. Indian Acad. Sci.* (*Bangalore*) (in the Press).
(11) Asundi, R. K., Jan Khan, M. and Samuel, R. *Nature, Lond.*, **136**, 642 (1935); *Proc. roy. Soc.* A, **157**, 28 (1936).
(12) Sharma, R. S. *Bull. Acad. Sci. Allahabad*, **3**, 87 (1933).
(13) Hunter, R. F. and Samuel, R. *Nature, Lond.*, **138**, 411 (1936) and literature mentioned there.

PRESENTATION OF THE FOURTEENTH DUDDELL MEDAL TO PROFESSOR WALTER G. CADY, 9 JULY 1937

THE PRESIDENT, MR T. SMITH, made the following remarks in presenting the medal:

The Duddell Medal is awarded to "persons who have contributed to the advancement of knowledge by the invention or design of scientific instruments, or by the discovery of materials used in their construction".

The Council of the Physical Society has awarded the fourteenth Duddell Medal to Walter G. Cady, Professor of Physics at the Wesleyan University, Middletown, Connecticut, U.S.A., for his work on piezo-electric resonators and oscillators as standards of frequency.

Prof. Cady's pioneer work on the subject was published in 1922 (*Proc. Inst. Radio Eng.*, **10**, 83) and the value of the device may be judged from the fact that it stimulated research work on the subject in all parts of the world, over a thousand papers having been published on the properties of piezo-electric crystals since the appearance of Cady's first paper. Of course, not all of these are due to Cady's researches, for Langevin had previously used piezo-electric crystals as vibrators for under-water signalling, but Cady's particular contribution—the use of the quartz resonator as a standard of time or frequency—has quite obviously inspired most of the work. The use of these resonators as standard vibrators has made it possible to measure frequency and intervals of time with an accuracy not previously attained. It is scarcely necessary to emphasize the importance to physics of increased accuracy in such fundamental measurements. Among the applications which have already been made the following may be mentioned: (1) The quartz-clock which is now used as standard in some observatories. It is in some respects superior to the pendulum clocks, and in any case is a most valuable supplement to them. (2) The measurement and control of the frequency of alternating currents in connexion with measurements of dielectric constant, absolute electrical measurements, and the like. (3) The measurement of the velocity of ultrasonic sound waves.

Duddell, who was responsible for so much elegant instrumental work, would have been the first to recognize the beauty of Prof. Cady's device, and it will be a source of great satisfaction to all scientific workers to know that the value of Prof. Cady's work has been recognized in such an appropriate manner.

OBITUARY NOTICES

PROFESSOR ALEXANDER ANDERSON

On 5 September 1936 died the able mathematician, physicist, and administrator who was widely known as "Anderson of Galway". He was an Ulsterman by birth and descent, but during nearly the whole of his life he was connected with the college in Connaught which was originally Queen's College and is now University College, Galway. He entered it in 1877 and graduated as B.A. and M.A. in the old Queen's University of Ireland. In 1881 he took an entrance scholarship at Sidney Sussex College, Cambridge. He came out Sixth Wrangler in the Mathematical Tripos of 1884, and in the following year went back to Galway as Professor of Natural Philosophy. In 1899 he was appointed President of the College, while retaining his Chair, and he continued to discharge the combined duties until his retirement in 1934. He then went to live in Dublin, where he had many friends and where he continued to take an interest in the proceedings at the Royal Dublin Society and the Royal Irish Academy. His death came as a shock to those who knew him, for he was a man over whom the years seemed to pass without making any appreciable diminution of his vigour of mind or body.

During the year which intervened between his Tripos and his return to Galway, Anderson worked in the Cavendish Laboratory, where Sir Joseph Thomson was then at the beginning of his Professorship. He is mentioned as one of the early workers of that time in the published history of the laboratory, but no indication is there given of the subject which occupied him. It seems probable, however, that he was interested in electrical measurements, for his first paper, published from Galway in 1891, was an account of the now well-known Anderson's method for comparison of inductances. In the same year he was elected to a Fellowship at Sidney Sussex College. Under Anderson and his colleagues on the mathematical side—Allman, A. C. Dixon, Bromwich, Houston, Power—Galway became an active centre of scientific teaching and research. His advanced pupils were few, but he gave them of his best and they drew from him inspiration as well as sound knowledge. The late Professor J. A. McClelland, F.R.S., was one of those who owed much to his teaching. Anderson's theoretical papers were the outcome and evidence of his thoroughness of method as a teacher. They are concerned with clearing up or simplifying some difficult matter of which the textbook treatment seemed to him inadequate, illogical or erroneous. He wrote, for example, on the motion of an iron ball in a magnetic field, on the quadrant electrometer, on the theory of moving charges, and on electrical distributions on two charged spheres. In his laboratory he kept experimental work going on questions which lay within the scope of his equipment, such as surface electrification, contact difference of potential, and measurement of surface tension and of the constants of lens systems.

Special reference should perhaps be made to the part taken by Anderson in the discussion of the results of the Sobral Eclipse Expedition in 1919. The observations were taken as affording confirmation of the Einstein deflexion, but he put forward the startling suggestion that the true cause of the observed effects was to be sought in the unequal heating of the earth's atmosphere during the passage of the moon's shadow. The matter was examined by Eddington, Crommelin, Dines, Richardson and Schuster. The outcome of their work was unfavourable to Anderson's theory, but he himself was not completely convinced.

Anderson was a man of very wide general culture. He was a fine linguist and read books on all sorts of subjects in many languages. His talk was full of humour as well as knowledge. He was a staunch and helpful friend, and a teacher who made friends of his pupils and who never forgot them.

W. B. MORTON.

PROFESSOR H. E. ARMSTRONG, F.R.S.

WHEN the Physical Society (of London) began in 1874, Armstrong was 26 years of age, and he was apparently sufficiently sympathetic to the science of physics to become a founder fellow, though his later contacts with that science seem to have been few. There is no record of his having read a paper to this Society, but he attended, and spoke, at the Jubilee celebrations in 1924, and his distinctive figure was not unknown on the occasions of the delivery of the Guthrie lectures. At that date (1874), four years after joining the Chemical Society, he had taken his Ph.D. degree at Leipzig, and was in charge of the chemistry classes for medical students at London. During this period he took an active part in the founding of the Institute of Chemistry, in the same year (1876) as he was elected a Fellow of the Royal Society. He lived to become the senior Fellow of the latter Society.

Later, he occupied the Chair of Chemistry at the London Institution, where the discovery of one of Sir William R. Grove's batteries first roused his interest in the general problem of chemical interchange, an interest which lasted until the end of his life and (in later years) left him as almost the sole opponent of the current theories of electrolysis, and therefore as the one chemist who resented the invasion of his subject by physics.

His next appointment was that of Professor of Chemistry at the City and Guilds Institute, first in temporary quarters at the Cowper Street Schools, Finsbury, and then, in 1883, at the City and Guilds College, South Kensington; this period lasted until 1911, when the College was fused with the Imperial College, and ceased to have its own Chemical department.

Armstrong is probably best known for his ardent advocacy of the view that "ordinary chemical actions...are themselves electrical", with the corollary that chemical reactions are nothing but reversed electrolysis. With this thesis, he never ceased to urge the view that solution is not something passive, but is a definite chemical reaction, and he fought violently against the orthodox treatment in which the ions are imagined as leading an existence almost independent of the solvent; in his opinion, the solvent and solute react, and are equal partners.

Apart from his purely chemical work—an investigation on the naphthalene series and another on the structure of camphor are probably the most important items—Armstrong will be remembered for his development of the heuristic method of teaching chemistry. This was first worked out during his tenure of the Chair at the London Institution, and was designed, in contrast to the didactic method, to train the student "to observe and think and act with clearly defined purpose, the work being carried out with common materials and in relation to common phenomena". In his hands the method worked well, and many of his pupils themselves reached some measure, greater or less, of renown. Nevertheless, the method is less in favour than it was, perhaps because it requires for its success an inner conviction, almost a missionary spirit, such as he had in abundance.

As an individual Armstrong was not well known to the present generation, to whom his love of polemics and his taste in dress clothes were the most familiar traits. The vigorous language of his letters to *Nature* and *The Times* will long be remembered. But his bark was worse than his bite, and does not represent the whole of his character. Actually he had a marked streak of the artistic temperament and was an enthusiastic opera-goer and a discriminating lover of pictures. This being so, we are not surprised to learn that gardening was one of his hobbies, though it may be news to some that another was field geology, to which he had made contributions. It throws light on his character to be told that in later years his favourite holiday centre was Borrowdale, though earlier he had been fond of continental travel (and did he ever rid himself of the idea that Germany was the only place in which chemistry could be really learnt?)

The span of his life was from 6 May 1848 to 13 July 1937, and during this time many honours came to him, among them the LL.D. of St Andrews, the D.Sc. of Melbourne and of Madrid, the Davy Medal from the Royal Society, the presidencies of various societies, including of course the Chemical Society, and medals from the Royal Society of Arts, the Society of Chemical Industry and the Institute of Brewing.

WILFRID NOEL BOND, M.A. (CANTAB), D.SC. (LOND.), F.INST.P.

THE untimely death of Dr W. N. Bond at the age of 39 has come as a great blow to his many friends. Modest, unselfish and entirely free from pretence, he radiated goodwill and endeared himself to all who came in contact with him. He was always ready to give of his best to all who consulted him, whether colleagues or students, and his advice on any problem in physics, however remote from his own particular interest, was always worth having. It would be true to say of him that his interest in other men's discoveries was at least as great as in his own. He will be missed by a much wider circle than he would have deemed possible.

Bond was born on 27 December 1897. Educated first at St Albans School, he received his early academic training at East London College and the Royal College of Science, graduating with first class Honours in the University of London, of which he subsequently became a Doctor of Science. His early academic studies were combined, during the Great War, with nearly two years' experience in industrial physics in the works of Messrs Kent, and his first publication (a joint paper with Mr J. L. Hodgson on the Fan dynamometer in 1916) dates from this period. It is probable that the interest in problems connected with the flow of fluids which inspired so much of Bond's later work was due to these early experiences.

Subsequent experience of research was gained at University College, London, under Professor Porter, and at the Cavendish Laboratory, Cambridge, under Professor Sir J. J. Thomson, where he graduated as B.A. by research. In 1921 he was appointed to the Lectureship in Physics in the University of Reading, which he continued to hold with distinction until his death.

Indefatigable in research, Bond has made numerous contributions to the pages of the *Proceedings of the Physical Society* and the *Philosophical Magazine*, not by any means all confined to one branch of physics. His main interest, however, was in the flow of fluids, and the related problems of viscosity and surface-tension measurements. With an unusual flair for experimental observation, he delighted in extorting from any given apparatus the maximum degree of accuracy of which it was capable, and all his experimental work is marked by an almost classical simplicity and elegance. His experimental insight and power of direction were maturing from year to year, and undoubtedly his latest work on the measurement of surface tension by a moving-sheet method and his recent determination of the viscosity of air represent him at his best.

Bond's interests in physics were by no means confined to his own experimental work, and his constructive analysis of the most probable values of the fundamental constants, undertaken in connexion with the theories of Sir Arthur Eddington, will be fresh in the minds of most readers. A strong, one might almost say mystical, belief in the fundamental unity and simplicity of the universe was a vital part of Bond's philosophy, and Eddington's theory moved him very deeply.

Bond was a kind, thorough and patient teacher, and was particularly successful in instilling into his students in the laboratory something of that love of accuracy and dislike of the slipshod which was such a marked characteristic of his own work.

In addition to his original work, Bond published three books, *Numerical Examples in Physics*, *An Introduction to Fluid Motion* and *Probability and Random Errors*. He leaves a widow and three children.

J. A. C.

JOHN FLEMING

MR JOHN FLEMING died at his home in St John's Wood, London, on 26 March 1937, in his 58th year.

Born in Scotland, on a moorland farm in the hills between Ayrshire and Lanarkshire, he came to London with his brother, Robert, to complete his education. Leaving school, the two brothers entered the optical industry and in 1905 founded the firm of J. and R. Fleming.

His journeyings abroad enabled him to acquire a deep knowledge of optical conditions outside Great Britain and to adopt and adapt many ideas formulated on his business travels, especially in the United States.

Members of his staff held him in true affection and esteem. He showed a paternal interest in their welfare, and there were many manifestations of a kindly and gentle nature in his business relationships.

He became a Fellow of the Optical Society in 1906, and a Fellow of the Institute of Ophthalmic Opticians in 1912.

DR GEORGE FORBES, LL.D., F.R.S.

DR GEORGE FORBES (or, as he was I think more commonly known, Professor Forbes) was born at Edinburgh on 5 April 1849 and thus was nearly 88 at the time of his death. His father was Professor of Natural Philosophy at Edinburgh and an F.R.S. when he was born, and was also one of the founders of the British Association. Later his father became Principal of St Andrews University, and it was here that Forbes was educated until he went to complete his training at Cambridge.

In 1872, that is when he was 23, he was appointed Professor of Natural Philosophy at Anderson's College, Glasgow, and there he remained until 1880. In the meantime, perhaps taking advantage of the long Scottish summer vacation, he was able to engage in several outside activities. For instance in 1874 he joined an expedition to Hawaii to observe the transit of Venus. The following year he crossed Asia from Pekin to St Petersburg by way of Siberia. Two years later during the Russo-Turkish war of 1877 he got himself appointed as a special correspondent of *The Times* and later in February 1930, when he was about 80, *The Times* published two articles by him in which he recounted his personal experiences.

About the end of this period, or about 1879, he was associated with James Young of Kelly in experiments to check previous determinations of the speed of light and to find if there were any differences in the speed for different colours.

In the meantime the telephone had been invented as well as the Gramme armature for dynamos and motors, and much attention was being given to the possibilities of electric lighting and traction. Forbes had already in lectures pointed out the possibilities of electric traction. He visited the Electrical Exhibition in Paris in 1881 and described it for *The Times*. In 1884 at the Philadelphia Electrical Exhibition there was exhibited a form of dynamo designed by him.

It was in connexion with his experiments on dynamos that Forbes, being troubled by sparking at the commutator, hit on the idea which has since revolutionized continuous-current practice both for generators and motors. It is only those who are old enough to remember when copper-wire brushes were used for collecting the current, and later brushes of copper gauze, the trouble and anxiety which these caused from their liability to heavy sparking resulting in cutting of the commutator. Faced with this trouble, Forbes hit on the idea of employing brushes of moulded graphite. These brushes had a double advantage, the higher resistance of the carbon prevented heavy sparking at any one point, and the graphite acted as a lubricator. Forbes for some reason did not patent this invention or discovery, but it soon began to attract adherents and when proper designs had been worked out gradually came into universal use. He always referred to this work with much modesty, but there can be no doubt that almost without acknowledgement he presented to the world an idea of great engineering and commercial value, the importance of which he does not seem to have fully grasped at the time.

Between 1884 and 1900 transformers in parallel, high voltages, and finally two- and three-phase motors were developed and became practicable, and the whole question of the possibilities of power-transmission and distribution over considerable areas began to receive serious attention. Forbes followed this work closely and when in 1900 the International Niagara Commission offered prizes for proposals for power-transmission from their proposed enterprise at Niagara, he put in plans for a scheme using two-phase current. Forbes was awarded a premium for this, though at the time the views of the Commission inclined to a continuous-current installation. The success of the Lauffen transmission at Frankfort in 1891, however, turned attention again to Forbes's proposals, and finally he was appointed one of the Company's consulting engineers on the understanding that the polyphase system would be adopted and that he should consider both the electric generating plant and the transmission to Buffalo. In connexion with this he designed a vertical form of alternator, the armature of which was fixed while the field magnets revolved outside it, thus forming a powerful flywheel. The practical engineering forms of these alternators were manufactured by the Westinghouse Co., and were the alternators used in the first generating station. Forbes later read a paper before the Institution of Electrical Engineers describing the installation, and his work is also referred to several times in the special issue of *Cassier's Magasine* which was devoted to a description of the Niagara installation.

It is worthy of note that even before the above work had been done Forbes had been asked to report on the best method of working the City and South London Railway, the first of the tube railways, and had recommended that it should be driven electrically.

Naturally Forbes's connexion with Niagara led to his being asked to advise as to the possibility of other water-power projects, and in this connexion he visited the Cape in 1895 and New Zealand in 1896, and in 1897–8 at the request of the Egyptian Government he made a study of the cataracts of the Nile with a view to their being utilized for electric power supply.

At this juncture the South African war took place, and this led Forbes to turn his attention to the design of range-finders, and one of his instruments was used in the war. Another gift of great value which Forbes gave to the nation was a very simple formula whereby the range table of a gun can be accurately calculated from that of another gun of a different calibre.

Forbes was now getting into the sixties and as his age increased his old interest in astronomy began to come to the front again; he lived henceforth most of the year at Pitlochry and devoted a good deal of time to writing and lecturing on the subject.

Either during this period or earlier he was the author of *Lectures on Electricity, Alternating and Interrupted Currents* and *Elektrische Wechselsstrome und Unterbrochener Strome*. He also wrote a number of works on astronomical subjects, including *The Transit of Venus, The Theory of the Glaciers of Savoy* and a biography, *Sir David Gill, Man and Astronomer*.

Towards the latter part of his life his eyesight failed very much and he came south and made his headquarters in Worthing. His books and papers he had given to St Andrews University.

Forbes was elected F.R.S. in 1887, he was also a Fellow of the Royal Society of Edinburgh and of the Royal Astronomical Society, and a member of the Institutions of Civil and Electrical Engineers, the Astronomische Gesellschaft, the Franklin Institute and the American Philosophical Society. He was an honorary LL.D. of St Andrews and held the Russian Order of St George and the French Legion of Honour.

G. L. ADDENBROOKE.

PROFESSOR ALBERT GRIFFITHS, A.R.C.S., D.Sc.

1867–1937

ALBERT GRIFFITHS was born at Chester in 1867. He received his scientific training at the Royal College of Science, South Kensington, at Owens College, Manchester, and at the University of Freiburg. He returned to Owens College as Demonstrator in Physics and Research Assistant to Schuster, and in 1893 was elected Berkeley Fellow. In 1898 he became a Lecturer in Physics at University College, Sheffield. From 1900, until his retirement in 1933, he was head of the Department of Physics at Birkbeck College, London, being appointed University Professor in 1922, shortly after the College became an Evening School of the University of London.

He became a Fellow of the Physical Society in 1896, and has served on its Council. His first contribution to the Society's *Proceedings*, a paper entitled "Diffusive convection", was made in 1898, and in it he struck the key-note of his future research. The paper excited the interest of Professor G. F. FitzGerald, whose subsequent letter to *Nature* probably served to confirm Griffiths in his determination to devote himself to the measurement of the coefficients of diffusion of salts in aqueous solutions. His work was characterized by extreme patience and scrupulous care. Some years of preliminary work were spent before in 1915 he was satisfied that his results had attained an accuracy warranting publication. Several methods of determination of the diffusion coefficient were devised, some being carried out by himself, some by his colleagues. A measure of accuracy in these difficult determinations was finally reached far exceeding that approached by previous workers in the subject.

His interest in slow movements in liquids was also manifested by his work on the coefficient of viscosity of water at low rates of shear. Observations were made of the rate of flow through capillary tubes under a pressure head of the order of a tenth of a millimetre of water. The conclusion was that the coefficient is sensibly the same as for normal rates of stream-line flow. These results (by two independent methods), like those on diffusion, were presented before the Physical Society; and on more than one occasion the author's work evoked a meed of praise from the President for its exemplary care and accuracy of execution. Griffiths had a persistent enthusiasm for research, and communicated this enthusiasm to those around him. Many good pieces of experimental work carried out by others in his laboratories were the fruits of his original suggestions. His kindly consideration and readiness to help will be long remembered by colleagues and students.

D. OWEN.

MR A. C. JOLLEY, A.M.I.E.E., F.INST.P.

BY the sudden death of Mr A. C. Jolley on 5 December 1936, a few months after his retirement from the headship of the Electrical Engineering Department of the Northampton Polytechnic Institute, Clerkenwell, technical education has lost one of its most valuable and earnest teachers. In spite of his having had little scientific education, his interest in physics led him to become laboratory assistant first under Prof. Cheshire and later under Dr Clay at Birkbeck College, where the present writer first met him in 1898 and was so impressed with his zeal and earnestness as to invite him to become lecture assistant in the Electrical Engineering and Applied Physics of the Northampton Institute. From this appointment he soon advanced to the position of senior demonstrator and lecturer and took a leading part in planning and equipping the electrical engineering and optical laboratories. Having great mechanical skill, he was of great assistance in developing the new electrical and optical instruments which were constantly being devized for extending the investigations in progress, on which he worked day and night. After the writer's retirement from the Northampton Polytechnic in 1910, Mr Jolley remained under Mr F. Denton, but he assisted the writer again in developing anti-submarine devices at the Admiralty Experimental Station at Parkeston Quay, where his technical skill was invaluable. After the death of Dr Walmsley in 1924 and the appointment of Mr S. C. Laws as Principal of the Northampton Polytechnic, Mr Jolley was appointed Head of the Electrical Engineering Department. The excellence of his general teaching was shown by the great success of his students, but his chief interest centred in electrical instruments, and he collaborated with the writer in a book on *Electrical Measuring Instruments* which involved careful dissection of numerous instruments, determining their properties, and making accurate drawings, all of which he carried out personally. His culminating work was the completion of a new instrument-making workshop in 1935, which stands as a monument to his careful planning. He developed considerable artistic skill, and his work was appreciated by several well-known artists.

Mr Jolley's retiring disposition and devotion to his department prevented him from taking any prominent part in scientific gatherings, but all his students and others with whom he came in contact soon came to appreciate the thoroughness and honesty of his nature. His loss will be severely felt by many instrument-makers who used to consult him on their problems, as well as by all his colleagues and past students, and above all by the present writer, by whom his unfailing help and devotion can never be adequately acknowledged.

C. V. DRYSDALE.

PROFESSOR THOMAS MATHER, F.R.S.

PROFESSOR T. MATHER was born at Higher Walton near Preston on 15 December 1856, and died in London on 23 June 1937. His career illustrates the public value of the Whitworth System of Scholarships. After attending a local church school he was apprenticed first to an engineering firm at Higher Walton and afterwards (1875–8) to a firm of engineers and boilermakers at Preston. During these years he attended evening classes at Preston. He started from home at 5 a.m. and did not usually return till after 10 p.m. He gained a Whitworth Scholarship, and at the age of 22 entered Owens College for a full-time engineering course which lasted for three sessions, 1878–81. At the end of the course he was awarded the Ashbury Scholarship in engineering. He continued his studies at the Royal College of Science during the session 1881–2. He became assistant to Professor Ayrton at the Finsbury Technical College in 1882, and in 1884 moved with Professor Ayrton to the City and Guilds Central Institution in South Kensington which is now part of the Imperial College. On Professor Ayrton's death he was appointed, in 1908, acting Professor and, in 1910, permanent Professor of Electrical Engineering. He retired in 1922 with the title of Emeritus Professor. When he died he was close upon 81 years of age.

He was elected Fellow of the Royal Society in 1902 at the age of 46. He was a Life Fellow of the Physical Society, a Member of the Institution of Electrical Engineers, and a Fellow of the City and Guilds of London Institute.

The most important papers which bear his name as part author are three printed by the Royal Society, two in the *Philosophical Transactions*, vol. **207** (1908), and a third in *Proceedings of the Royal Society*, vol. **80** (1908). They are entitled "A new current weigher, and a determination of the electromotive force of the normal Weston cadmium cell"; "The silver voltameter"; and "The comparison of the Board of Trade ampere-standard balance with the Ayrton-Jones current weigher, with an appendix on the electromotive forces of standard cells". The authorship of the first paper was shared with Professor Ayrton and F. E. Smith (now Sir Frank Smith), and that of the other two papers with Sir Frank Smith.

These papers represent part of work of the first importance which resulted in the setting up of the national standards of current and of electromotive force. Such work necessitated not only most accurate experimental measurements but also the investigation of an almost endless number of practical details, proper attention to which was essential for the production of satisfactory standards. From the papers themselves it is not possible to judge the part undertaken by Professor Mather, but there can be no doubt that it was a most important one. His thoroughness, close attention to detail, and powers of initiative were qualities needed in order to carry out such work satisfactorily. The investigation was a continuation of work of the same type carried out by Professor Ayrton for some years in conjunction with Professor Viriamu Jones. Professor Mather was in intimate touch with all the work done in the College laboratories. His election to the Fellowship of the Royal Society in 1902 was an indication of the value of his help in laboratory investigations, and also a recognition of his work in connexion with the improvement of electrical instruments. He was a skilful mechanic, a good designer, and a ready deviser of teaching appliances. His interest in science was more concerned with its industrial application than with its theoretical development. He was not a writer of papers. There does not appear to be a single paper of which he was sole author.

His name in association with that of Professor Ayrton appears on many papers dealing with improvements in the construction of electrical instruments and accessories. Three papers on galvanometers were read before the Physical Society and printed in the *Philosophical Magazine* for July 1890, November 1896, and October 1898. Two others are to be found in vol. **23** of the *Proceedings of the Institution of Electrical Engineers* and are entitled "A universal shunt box for galvanometers" and "An astatic station voltmeter". The Ayrton-Mather shunt was highly appreciated and is in very common use. The electrostatic voltmeter is due to the skilful design of Professor Mather, and the first forms of it were constructed with his own hands. These voltmeters have been extensively used in practice. The precision Wattmeter of Mather and Duddell is another instance of the excellence of Mather's work. First-rate instruments and appliances, suitable for college or industrial testing, are now commonplaces of commerce, but industrial laboratories are quite a recent development and before such excellent results could be reached commercially it was necessary for much previous work to be done in laboratories established for technical teaching. Mather was one of the earliest and ablest pioneers in such work.

When Mather joined Professor Ayrton's staff in 1882 electrical engineering was an entirely new industry. There were no college departments providing a training for it, and trained men did not exist. There was a sudden demand for evening classes to train large numbers of adult students for work in the new industry. The development of suitable courses and training appliances called for much initiative and ability. Professor Ayrton at first directed this work but later on was content to leave it almost entirely in the hands of his capable assistant. The work grew in volume and developed in scope with the transfer from the Finsbury College to that at South Kensington, with the establishment of three-year college courses, and with the rapid development of electrical engineering. The main work of Mather's life consisted in the development of these laboratories and in the constant help given by him to those who worked in them, whether as ordinary students or as exceptional research students.

For many years Mather's speech suffered from an impediment so serious that he could not lecture or take part in public discussions. Had he been able to do so he would have been more fully appreciated outside the college than he was. Fortunately he was at length able to overcome this defect and to lecture in a way highly thought of by his students. In his nature he was most modest and retiring. He was always kindly and willing to help in either simple or advanced work. He was much liked personally and was held in honour by all who knew him.

W. E. SUMPNER.

JOHN ALBERT MORROW

MR JOHN ALBERT MORROW was born at Bedford Park, London, on 28 April 1902. His early education was at St Paul's School, Southdown College and Brighton College, after which, in 1921, he entered the Royal College of Science. In 1924 he was awarded the Associateship of the College in Physics, and in 1925 the Diploma of the Imperial College for advanced study and research in spectroscopy under the supervision of Professor A. Fowler. On leaving South Kensington he took up an appointment at the Shirley Institute of the British Cotton Industry Research Association at Didsbury, Manchester, and continued in that position until his death on 25 May 1936.

Mr Morrow acquired considerable skill in experimental work, and at the Shirley Institute was especially noted among other members of the staff for his ingenuity in the design and construction of working models of testing-apparatus of various kinds which were subsequently turned out in more permanent form in the workshop. Unfortunately he suffered from poor health during a large part of his life, but he nevertheless always maintained a cheerful disposition. He leaves a widow, but no children.

He was elected a Fellow of the Physical Society in 1926 and an Associate of the Institute of Physics in 1933.

A. FOWLER.

JAMES RICE, M.A.

MR JAMES RICE, M.A., who died on Friday, 17 April 1936, at the age of 62, was Associate Professor of Physics and Reader in Theoretical Physics in the University of Liverpool.

After a very distinguished career at Queen's College (now the Queen's University), Belfast and in the Royal University of Ireland, where he obtained the highest honours in mathematics and mathematical physics, he was appointed in 1902 Senior Physics Master at the Liverpool Institute. In 1914 he was appointed to a Senior Lectureship in Physics in the University of Liverpool. His excellent work at this University secured for him the title and status of Associate Professor in 1924, and the additional title and status of Reader in Theoretical Physics in 1935.

Rice's early interests lay chiefly in the fields of thermodynamics, kinetic theory, and statistical mechanics. His mastery of these subjects is shown by his excellent

Introduction to Statistical Mechanics for Students of Physics and Physical Chemistry (Constable and Co., 1930), and by the important articles on "Strained elastic solids" and "Surfaces of discontinuity", which he contributed to vol. **1** (Thermodynamics) of the *Commentary on the Scientific Writings of J. Willard Gibbs* (Yale University Press, 1936).

The newer developments of theoretical physics appealed strongly to Rice's eager and receptive mind. His mastery of the general theory of relativity was demonstrated by the publication of his *Relativity; a Systematic Treatment of Einstein's Theory* (Longmans, Green and Co., 1923). This excellent book dealt with the complete mathematical theory of the subject, and soon became a valuable textbook for advanced University students of theoretical physics. His popular book on *Relativity* in Benn's well known sixpenny series had an extensive sale, and did very much to spread a knowledge of the new concepts in the minds of the general English-reading public.

To vol. **3** of Professor Lewis's well-known *System of Physical Chemistry* (Longmans, Green and Co., 1924) Rice contributed valuable appendices dealing with Maxwell's distribution law and the principle of equipartition of energy, quantum theory, and the correspondence principle.

Rice possessed a clear and logical mind, a sound knowledge of mathematics, and a wonderful gift for lucid exposition of the principles of theoretical physics. His unselfish devotion to teaching and the heavy burden of being almost the sole representative of modern physics in the University of Liverpool during many years left him little time for original work, so he devoted himself to the task of mastering and expounding to his students the great discoveries and principles of physical science during 33 years (1902–35) of almost miraculous development—a development too overwhelming in its abundance for one man. The success which he achieved in this great work is only very partially revealed in his books, excellent though they be. Like many another good teacher, his success and his reward dwell in the grateful hearts and illuminated minds of those whom he taught, and of the many colleagues and friends who derived knowledge and inspiration from a mind and spirit well informed, generous, and forgetful of everything save the progress of the knowledge and well-being of mankind.

F. G. DONNAN.

JOHN ROSE-INNES, B.A., B.Sc.

JOHN ROSE-INNES was a Fellow of University College, London, a graduate of Cambridge University, and a member of King's College. He served on the staff of the Department of Physics, University College, London, from 1889–90 to 1892–3. He took a keen interest in experimental work, but not being naturally endowed in that direction confined himself to the mathematical treatment of such problems as interested him. His very considerable skill in this is illustrated by two papers, one on the motion of a pendulum through an arc of finite magnitude(1) and the other the integration of the differential equation applicable to a plane progressive wave(2).

The rest of his work is more directly connected with some practical problem. Besides a slight paper⁽³⁾ on the ratio of the two specific heats of air, there is a paper⁽⁴⁾ on the physical interpretation of the Michelson-Morley experiment. In a series of papers⁽⁵⁾ the isothermals of ether, pentane, and isopentane are obtained, on the basis of Ramsay and Young's experimental results.

But the work in which Rose-Innes took the most interest was the practical attainment of the thermodynamic scale of temperature. At the time with which we are dealing, only the Joule-Thomson results on the porous plug experiment were available. It will be remembered that Kelvin interpreted these results as indicating that the Joule-Thomson effect was inversely proportional to the square of the absolute temperature. In an early paper⁽⁶⁾ Rose-Innes was the first to call this assumption into question, adopting a formula involving a constant term and a term inversely proportional to the temperature. The formula thus involves two constants, but allows an inversion point. With this assumption the constant-volume gas thermometer required, to a first approximation, no correction of its readings; the correction to the constant-pressure thermometer was worked out. Applying these formulae to the known experimental results for hydrogen and nitrogen, Rose-Innes did not obtain, for the value of the melting-point of ice on the thermodynamic scale, the consistency he expected. In a second paper⁽⁷⁾ the equations were recast to avoid extrapolation of the Joule-Thomson effect, while the isothermal compressibility of the gas used was assumed as known through the same range as this effect. In a third paper⁽⁸⁾ the isothermal compressibility is taken as known at one temperature only, an assumption more in accord with figures at our disposal. The values for the melting-point of ice were in better agreement than before, but still, in his opinion, unsatisfactory. In a further paper⁽⁹⁾ with great ingenuity Rose-Innes recast his equations so that the actual numerical values of the Joule-Thomson effect were not assumed, but only their general form. In this paper the values obtained from the hydrogen and nitrogen thermometers were 273·04 and 273·13 respectively. The difference between these two values was even then considered larger than the experimental results would appear to warrant, and was attributed to a possible influence of the material of the containing vessel. In a final paper⁽¹⁰⁾, with the conviction that the discrepancy was to be attributed to the uncertainty of the values for the Joule-Thomson effect, he again recast his equations so that only relative values of this effect were made use of. The values now obtained were 273·131 and 273·136. The Leiden Laboratory's latest (1936) value is 273·14.

Rose-Innes was never a strong man, and the privations of the war considerably weakened his health and undermined his working-power. He published nothing after the war, and passed away at Bournemouth on 9 July 1933, at the age of 68.

N. EUMORFOPOULOS.

REFERENCES

(1) *Phil. Mag.* **6**, xix, 851 (1910).
(2) *Phil. Mag.* **7**, xxvii, 669 (1914).
(3) *Phil. Mag.* **5**, xlviii, 286 (1899).

(4) *Phil. Mag.* **6**, xxvii, 150 (1914).
(5) *Phil. Mag.* **5**, xliv, 76 (1897); xlv, 102 (1898); xlvii, 353 (1899); xlviii, 213 (1899); and **6**, ii, 208 (1901).
(6) *Phil. Mag.* **5**, xlv, 227 (1898).
(7) *Phil. Mag.* **5**, l, 251 (1900).
(8) *Phil. Mag.* **6**, ii, 130 (1901).
(9) *Phil. Mag.* **6**, vi, 353 (1903).
(10) *Phil. Mag.* **6**, xv, 301 (1908).

JOSEPH HERBERT VINCENT, M.A., D.Sc., A.R.C.S.

Dr J. H. Vincent, who died on 27 January 1937, served on the Council of the Society from 1920 to 1924 and was a Vice-President from 1925 to 1927; he also served on the Board of the Institute of Physics from 1925–9. He began his studies in physics at the Mason College, Birmingham, under Professor Poynting, and afterwards proceeded to the Royal College of Science, London, where he studied under Rucker and Boys, gaining the Associateship in 1895. After serving as a Demonstrator at that College for a short period he went to the Cavendish Laboratory, Cambridge, where he was engaged in research work under the direction of J. J. Thomson. After leaving Cambridge he became Head of the Physics Department at the Paddington Technical Institute, a position he retained until his retirement in 1934.

Vincent's published researches always represented work of a high order. His method of photographing ripples, generated on the surface of mercury by a glass style attached to one prong of a vibrating tuning-fork and dipping into the mercury, was published in volume **15** of the *Proceedings*. By attaching a second style to the same prong he was able to generate two sets of waves in the same phase, and to photograph the effects of interference on the ripples produced. These experiments immediately became popular, and associated Vincent's name with this branch of physics. Unfortunately his duties allowed him little time for the prosecution of research, and he was unable to follow out several lines of work which he had planned. In 1918, however, he was freed from his duties at Paddington, and joined Professor Eccles at Finsbury Technical College in what was then the Admiralty's Electrical Laboratory in London. One of the first problems he took up was that of the inconstancy of the frequency of the oscillations generated by triodes in back-coupled circuits of various kinds; and he succeeded in devising methods of keeping the frequency extremely constant, the results being published in a joint paper with Eccles in the *Proceedings of the Royal Society*. Whilst at Finsbury he also investigated certain troubles in heterodyne reception with triodes, and the production and reception of supersonic waves in water. In the latter connexion difficulty in obtaining quartz led Vincent to consider the possibilities of magnetostriction in nickel, but owing to the resumption of his teaching duties he was unable to follow out his ideas in this direction. He took up the work again with great success in 1925, and later read several papers before the Society describing his results.

During his later years Vincent was dogged by ill health, which caused his early retirement and put an end to his investigations. All who had the privilege of working with him found him a most estimable colleague, and will remember him as one who planned his work so thoughtfully that the experimental test of his project was almost always successful at the first trial.

C. R. DARLING.

RICHARD SMITH WILLOWS, M.A., D.Sc.

On 10 January 1937 a life devoted to the interests of physics and physical research came to an end by the death of Richard Smith Willows, M.A., D.Sc., at the age of 61. Born in the village of Foston, near Grantham, Lincolnshire, a member of a farming family, R. S. Willows was educated first at the village school and later at Sedgebrook Grammar School, subsequently proceeding to Nottingham University College, and thence to Cambridge University. At Nottingham he came under the influence of the late Professor E. H. Barton, F.R.S., D.Sc., whom he always held in the highest esteem. From Nottingham, after graduating in the University of London, he proceeded to Trinity College, Cambridge with an 1851 Exhibition, where he did research in the Cavendish Laboratory in association with Sir J. J. Thomson, O.M., F.R.S., whose inspiring influence made a profound impression upon him. Willows was destined to spend a large part of his life as a teacher of physics, for which profession he had ability of a high order. He was for a short time Lecturer in Physics on the Staff of Battersea Polytechnic, and from 1902 until 1918 occupied the post of Head of the Department of Mathematics and Physics at the Sir John Cass Technical Institute, London. During his tenure of the latter post many of his students caught his enthusiasm for the subject of which he was a master, and not a few owe their success in life largely to him. His lectures were always lucid and replete with interest, and the fascinating lecture experiments which he devised and prepared were the admiration of all who were so fortunate as to come under his tuition. But it will perhaps be by his admirable work in the laboratories, and especially in research, that his students will remember him best. He was always ready to help them when in difficulties, however insignificant, and the charm of his personality and his kindly, sympathetic manner made him beloved by all who came into close contact with him. His knowledge of published researches was profound.

The great war provided an opportunity for Willows's skill in and knowledge of physical research to be utilized in the service of the country. Selected specially on account of his excellent work on the conduction of electricity through gases, Willows was enabled to conduct researches which led to the perfecting of the manufacture in this country of X-ray tubes. It was largely as a result of these researches that the supply of X-ray tubes to the Services was maintained at a time when importation was a matter of extreme difficulty. As a result of this work, unobtrusively performed, his ability to deal with research problems in applied science was recognized, and in 1918 he was appointed as Head of the Physics

Department in the newly established research laboratories of Messrs Tootal, Broadhurst, Lee & Co., of Manchester. So successful was he in solving some of the difficult problems of the cotton industry in a much shorter time than was expected, that he was soon promoted to take complete charge of the firm's research laboratories, and in the later years of his life he became a director of the company.

His outstanding achievement was perhaps his successful solution of the problem which had baffled the industry for many years, that of producing a cotton fabric which would not crease. The utility of cotton cloth was widened enormously by this discovery, and thousands of workers benefited at a time of acute trade depression through there being placed upon the market a cotton fabric which could compete with fabrics made of other textile materials. The discovery was a triumph for R. S. Willows and his staff as well as of the application of scientific research to industry. Amongst the other scientific studies in which he excelled was that of colloids. One of the first to organize a course of lectures in this subject in his Department at the Sir John Cass Technical Institute, he was afterwards closely associated with the establishment of a Chair of Colloids in the University of Manchester.

The part which recreation played in Willows's life contributed to no small extent to his success. He knew when to work and when to play. He was keenly interested in reading history, and was an enthusiast at golf. He was twice married, first to Miss Kemp of Sedgebrook, Lincolnshire, and four years before his death to his second wife, who survives him. He leaves also a son and daughter, and many friends to mourn his loss.

F. J. HARLOW.

SYDNEY YOUNG, F.R.S.

1857–1937

SYDNEY YOUNG, the son of a Liverpool merchant, was a Lancastrian, born at Farnworth on 29 December 1857. He was trained in chemistry under Roscoe and Schorlemmer at Owens College, and under Fittig at Strasburg, where he developed that skill in glass-blowing which stood him in such good stead in his later work.

His outlook on his science was distinctly physical, and this bias, it has been suggested, may have arisen from an early demonstration which he gave to the Chemical Society at Owens College of Carnelley's discovery that the application of very considerable heat fails to liquefy ice at very low pressures.

Be this as it may, the physical world owes much to Young's careful investigations of the thermal properties of pure liquids—a long-continued series of researches which culminated in his famous paper of 1910 (published in the *Proceedings of the Royal Dublin Society*) wherein he tabulates the vapour pressures, specific volumes and critical constants of some thirty carefully purified compounds. In this and in earlier papers he discusses the law propounded by Cailletet and Mathias that the mean of the orthobaric densities of the liquid and its saturated vapour is a linear function of the temperature. The only substance for which Young found this to be strictly true was for *n*-pentane. For all other substances the law of rectilinear diameters is no more than a convenient approximation, and the march of the *mean* density (ρ) with temperature is better represented by

$$\rho = \alpha + \beta t + \gamma t^2,$$

where γ is small, but appreciable.

Young was much interested in boiling point relations in homologous series and established a useful general formula giving the difference (Δ) between the boiling-point of one homologue and the next in the series in the form

$$\Delta = A/T^{B\sqrt{T}}.$$

His work on the problem of distillation is classical in quality.

Young succeeded Ramsay in the Chair of Chemistry at Bristol in 1887. On the retirement of Emerson Reynolds in 1903, he was appointed to the Chair of Chemistry at Trinity College, Dublin, a position which he held with distinction until his retirement in 1928. He was elected to the Royal Society in 1893.

It was not the fortune of the present writer to know Young personally. Many years ago, however, he wrote to Young for assistance in certain physico-chemical problems and he has very happy memories of a correspondent who was most friendly and helpful, and who spared no pains in elucidating the difficulties of a young research student.

A. F.

The Council have learned with profound regret of the loss which has been inflicted by the death of Lord Rutherford upon physics and upon his many friends in the Physical Society. A biographical notice of Lord Rutherford will be published in the *Proceedings* of the Society at a later date.

REVIEWS OF BOOKS

Principles of Quantum Mechanics, by Alfred Landé. Pp. xii+117. (Cambridge: University Press, 1937.) 7*s*. 6*d*. net.

In reading this short account of the principles of quantum mechanics one cannot fail to appreciate the fact that the author has thought about the subject in his own particular way and has resolved a number of difficulties which originally presented themselves to him. Having thus thought and learned much about the subject he decided to write a book upon it. This is the proper sequence of events in the development of a book and it cannot fail to produce a work bearing the characteristics of an original thinker.

Professor Landé's object in writing this addition to the literature of the quantum theory has been principally to eliminate some non-physical confusions which have crept into it and to show that it is based wholly on physical ideas.

The book takes as its text the complementarity of waves and corpuscles, and by means of individual examples, treated from both points of view, the quantum theory is presented as a method for translating corpuscular data into wave data and vice versa. The relations necessary for connecting the apparently antagonistic conceptions of the two points of view emerge very simply and clearly in the examples.

The second of the five parts into which the book is divided is devoted to the uncertainty principle. This is examined very thoroughly, and the treatment is based upon the introduction of an amplitude variation in the form of the Gaussian error curve. The more familiar method of introducing the principle by means of the theory of optical instruments is probably more acceptable to many physicists, but the method chosen here is not so widely known and has the advantage of giving greater mathematical precision to the principle, while it fits better into the plan of the book.

The later parts of the book, which include a discussion of the principles of interference and of correspondence, are especially useful as an explanation of the mathematical apparatus of the more advanced parts of the theory, and on account of the precision given to terms often loosely used, such as "interference of probabilities" and "probability packets". The work is certain to appeal to those who have already a good knowledge of the quantum theory and they will find in following the line of thought of the author a clarity and precision in the physical ideas not always to be found in works on this subject. H. T. F.

Atomic Spectra and the Vector Model, by A. C. Candler. Volume I: *Series Spectra.* Pp. viii+237. Volume II: *Complex Spectra.* Pp. vi+279. (Cambridge: University Press, 1937.) 15*s*. net each volume.

As is pointed out in the preface to these volumes, the empirical laws forming the basis of present knowledge of atomic spectra were originally stated in notations that now seem cumbrous and even misleading, and no adequate review of the earlier work on series spectra has appeared in this country since the universal adoption, in 1929, of the relatively simple and more convenient modern notation. In Prof. A. Fowler's *Report on Series in Line Spectra*, which was published by our Society in 1922 and is the one English work to which reference must still be made for ground-work and data, we encounter one of the old notations which we now wish to forget.

In the first volume, dealing with series spectra, this omission in regard to notation is repaired, and an account is given of the splitting of atomic lines in magnetic and electric fields, this being essential to a complete understanding of the series laws. The last two chapters of this volume deal with such matters as the periodic table, valency and co-valency, X-ray spectra and the doublet laws.

In the second volume, dealing with complex spectra, the theory is developed, the spectral types are described, and recent topics, such as hyperfine structure, quadripole radiation and fluorescent crystals, are taken up one after another. So much research is now concentrated on matters discussed in this volume that some of the statements made will, unfortunately, very soon need revision, notably in regard to the rare earths in view of Albertson's investigations.

The argument is entirely within the easy comprehension of all physicists, physical chemists and spectroscopists with no more than ordinary mathematical equipment, for not only is the vector model used throughout, but also, wherever the predictions of the model have been refined by means of the quantum mechanics, the results are freely quoted and compared with observational data, and the rather heavy mathematical proofs are entirely excluded. The plan adopted is first to present experimental facts and then to introduce the theory as a means of correlating them; this is the order in which the subject has been developed and that in which many spectroscopists still prefer to approach it. These at least will be grateful to the author for his decision to avoid the opposite plan—which has been favoured by several modern writers on both atomic and molecular spectra, and would, doubtless, have been quite easy to the author—of presenting, in outline at least, the principles of the quantum mechanics and the special results of the general theory and afterwards comparing these with experimental facts. The latter plan is more suited to a theoretical treatise such as the excellent one by Condon and Shortley, *The Theory of Atomic Spectra*, which came from the same press two years ago, than to a book for the beginner or one for the experimental physicist. Judging by the opinions which are being expressed by several actively engaged spectroscopists who have examined Candler's volumes during the summer vacation, it seems safe to predict that many readers will prefer them to any other recent introduction to atomic spectra.

Amongst other merits of this scholarly work, mention must be made of the beautifully clear style in which it is written and the care which has been devoted to the bibliographies at the ends of the chapters and in appendix VI. Not content to give a list of bare references, the author adds notes indicating briefly the topic of each paper, the scope of each book, and the conversions from the older notations used in some of the papers into the modern notation. The text contains numerous tables and line diagrams and is illustrated by eight plates of well-chosen spectrograms. Each volume is adequately indexed and, needless to say, excellently produced by the Cambridge University Press.

W. J.

Atomic Spectra and Atomic Structure, by GERHARD HERZBERG. Pp. xiv + 257. (London and Glasgow: Blackie and Son, 1937.) 18*s*. 6*d*. net.

This is an English translation, by J. W. T. Spinks with the co-operation of the author, of Herzberg's *Atomspektren und Atmostruktur: eine Einführung für Chemiker, Physiker und Physikochemiker* (Dresden and Leipzig: Steinkopff, 1936), which appeared so recently that it is unlikely to have become well known in this country. It is smaller and less detailed than either of the other two English introductions to this subject that have appeared recently, namely White's *Introduction to Atomic Spectra* (1934) and Candler's *Atomic Spectra and the Vector Model* (1937). In order to meet the requirements of beginners and of those seeking some knowledge of the subject on account of its applications to other branches of knowledge, the author lays stress on fundamental principles and makes no attempt to satisfy the needs of practical spectroscopists by the inclusion of tables of numerical data and discussions of special cases. This omission may be welcomed rather than deplored, since such material is to be found in the two larger works. As in those works, a statement of experimental results relating to a given topic precedes the theoretical treatment, complicated mathematics is avoided, and theoretical results are quoted without rigid proof. This, too, is a good feature, as the full treatment is now at hand in Condon and Shortley's *The Theory of Atomic Spectra* (1935). Nevertheless, a good and comparatively long wave-mechanical section follows the early sections on Bohr's theory of the H spectrum in chapter I, and shorter ones are included in the discussions of the He spectrum in the same chapter, the normal Zeeman effect in chapter II, and Pauli's exclusion principle in chapter III. These theoretical sections and certain other discussions are printed in smaller type than the rest of the text, as an indication that they may well be omitted in a first reading without loss of grip of the argument. In view of the applications, especially to the investigations of molecular spectra and molecular structure, certain topics are dealt with at greater length than others that would appear to be more important to the study of atomic spectra alone; for example in the last chapter (VI) there are sections on ionic (heteropolar) and atomic (homopolar) binding and elementary chemical processes. The book is well illustrated with line diagrams, tables and spectrograms, and is well indexed. The English edition is better printed and produced than the original, and in the course of its preparation the author has improved upon the original presentation in several places. The reproductions of typical photographs of White's electron-cloud models in figure 21, however, are not quite as good as in the German edition and not nearly as good as those in White's book (p. 71).

W. J.

Atomic Structure of Minerals, by W. L. BRAGG. Pp. xiii + 242. (Oxford: University Press.) 18*s*. net.

This book is a review of the investigation of the atomic structure of minerals by means of X rays. Professor W. L. Bragg was the first to analyse the structure of a mineral by such means, since in 1913 he determined the positions of the carbon atoms in diamond, and many of the results described in this book are due to him and to his co-workers. Their well-known work on the silicates may be mentioned as an example.

The greater part of the book consists of a description of structures; a list of headings will give some idea of its scope. The elements are treated, and the halides, the sulphides, arsenides, oxides and oxygen salts, the silicates and alumino-silicates, the pyroxene and amiphole groups and the mica and clay groups, the felspar group, and the zeolites and other framework structures. The book is fully illustrated, and the author shows his usual talent for making the most complicated structure clear. Many physical properties of various minerals, besides their actual structures are discussed and related to the latter; for instance, the twinning of the felspars and the refractive indices and birefringence of calcite and aragonite.

The book contains also three introductory chapters on the geometry of crystal patterns, the analysis of crystals by means of X rays and an especially interesting one on the general principles of mineral structure. This chapter gives a very clear account of Pauling's principles in ionic structures, according to which, in the specially stable structures taken up by all natural minerals, the lines of force starting from any ion must always end on a nearest neighbour. This rule imposes a most rigorous condition upon the geometrical configuration of a structure, and is constantly referred to in the book. The printing of the book, and especially of the figures, is excellent.

N. F. M.

Electricity and Magnetism for Degree Students, by S. G. STARLING. Sixth edition. Pp. 630, with 449 diagrams and illustrations. (London: Longmans, Green and Co.) 12*s*. 6*d*. net.

The appearance of a new edition of this well-known textbook deserves notice. The new format, with its larger type and page, first strikes the eye. The total content of the book is also slightly greater. Some matter is omitted, new matter is introduced, and minor corrections here and there indicate that the whole book has received careful revision. The essential character of the work remains, however, unchanged, and on this the author can be congratulated. The difficulty of writing a textbook to cover a degree course in this branch of physics is quite obvious, in view of the immense rate of advance in so many directions in recent years. It is above all necessary that the student should acquire a firm command of fundamentals in respect of facts, instruments, and principles, before he engages in the exploration of the fascinating but lengthy pathways of the newer knowledge. The author has by no means ignored the later developments, and place has been found for many new sections. To give some instances: Langevin's theory of paramagnetic bodies and Weiss's theory of ferromagnetic bodies, the Stern-Gerlach experiment, electron optics, the neutron, the positron, cosmic rays, artificially induced radio-activity, the ionosphere, the Compton effect. But the author's primary consideration has been to retain intact the adequate treatment of what is customarily designated "classical" physics.

It is, of course, a facile exercise to compile lists of what one would like to see included, and to advise on the omission or reduction of certain sections. Yielding to the impulse, the reviewer would suggest for inclusion in a future edition: Dye's method of determining the vertical component of the earth's magnetic field, the electric dipole and its place in dielectric theory, Professor E. Taylor Jones's work on the induction coil, the ruled grating method of measuring the wave-length of X rays and the refractive index for X rays, the work of Dempster and of Bainbridge on positive rays. The task of making compensatory exclusions should not be insuperable.

This is a textbook, then, which has the merit of laying the stress on the classical ground of electricity and magnetism, on both the theoretical and experimental sides, whilst presenting the later advances, so often involving the quantum idea, in briefer setting. A literature is now available affording sources of information on the various branches constituting the modern side, so that the specialist student may readily supplement his knowledge in any direction.

D. O.

Gases and Metals, by COLIN J. SMITHELLS. Pp. vii + 218. (London: Chapman & Hall.) 18*s*. net.

When a gas atom strikes a metal surface it may, if not reflected again, either stay on the surface, or penetrate into the body of the metal and remain there, or emerge at the other side. The book under review devotes one chapter to each case, i.e. to adsorption, to solution and to diffusion. On reading the book, one is impressed by the rapidity with which events now move in physics, for the outlook in each chapter is one which could not have been conceived twenty-five years ago. In adsorption problems, as in the analogous problem of films on liquids, the work of Langmuir is of fundamental importance, and directs attention to the individual molecule and its relationships with the metal atoms. The question whether a molecule can migrate from place to place would once have seemed impossible of answer, but here it is dealt with as quite an ordinary question. Again, in solution, we are no longer forced to be satisfied with empirical laws true in bulk. Once more, the new knowledge requires us to answer the question as to how the foreign molecules are located relatively to the metal atoms, and once again an answer is forthcoming. Even the diffusion problem raises the question as to the route by which the molecules migrate through metal. Do they pass between the atoms in the lattice, or through the cracks between crystals? These reflections may suggest that the book is devoted to pure or academic physics, but whilst this may be true, it is none the less useful, and much of the information with which it is packed has in fact been obtained for direct industrial application.

The book is printed on very thick paper, and is profusely illustrated, containing more than two diagrams for every three pages of text.

J. H. A.

Tables of Physical and Chemical Constants, by G. W. C. KAYE and T. H. LABY. Eighth edition. Pp. 162. (Longmans Green.) 14*s*. net.

A quarter of a century has elapsed since the first appearance of this book of tables. Many will remember it as a slim volume with flexible covers easily slipped into a pocket. On reaching the eighth edition it has inevitably grown more portly, but the authors are to be congratulated on having succeeded in keeping it still within reasonable limits. The present edition shows evidence of considerable revision and, apart from major changes, examination of almost any page will show alterations where a more recent determination has replaced an older value of a constant. A noteworthy change is on pp. 40 and 41, where the earlier hygrometric tables, which included Glaisher's factors, have been replaced by a set of tables for the wet-and-dry-bulb hygrometer which cover the temperature-range from $-18°$ to $+100°$ C. On turning over the page from this table, another completely recast table is found, viz. that for the boiling point of water at pressures from 680 to 780 mm. This table, to 0·001° C., replaces the older one which was to 0·01° C. only, and is in terms of the international temperature scale, instead of the hydrogen scale. Incidentally, it is interesting to note that room has been found for the vapour pressure of heavy water at two temperatures. The section on temperature-measurement, too, has been largely rewritten, and new values are given for the thermodynamic temperature of the ice point, the corrections to mercury-in-glass thermometers and the e.m.fs. of typical thermoelements. The four pages devoted to magnetic data have been almost completely rewritten, and the fact stated in the preface that Mr C. E. Webb of the National Physical Laboratory has assisted with them is a guarantee that the selection of materials is a useful one.

A completely fresh system has been adopted for the tabulation of the X-ray spectra, including the K and L absorption edges, whilst other constants of modern physics have been added or revised. Thus, the X-ray grating methods for determining e are mentioned, as is Kellström's recalculation of Millikan's data using recent values for the viscosity of air. That ubiquitous element, heavy hydrogen, appears in connexion with the value of e/m for electrons, having been used for a spectroscopic determination. The Abraham electron has disappeared, and in its place is a table of the exit work functions of a few important metals, whilst ionizing and resonance potentials have been introduced for the first time on p. 111.

On the last page of the book, again, is an almost new table, in which the individual isotopes of each element are set out. A reviewer elsewhere has expressed his regret that abundance ratios were not included, but it is difficult to see how the authors could have included these unless they had abandoned the attempt to set out the 92 elements on a single page. The remaining changes in the sections on general physics and heat appear to be restricted to minor improvements in data, due in the main to the publication of new determinations.

The acoustical section, as befits the new outlook on acoustics, has been appreciably altered, and the book now contains an explanation of the bel and the decibel, as well as data for the variation in sensitivity of the normal ear over the frequency range 20 to 20,700 c./sec. In the section on the velocity of sound, an error has crept in, whereby Sherratt and Ezer Griffiths are credited with a value for the velocity of sound in air at 1800° C.; actually, no data are available for air from any source at such temperatures, and the authors of the tables have informed the reviewer that the entry will be deleted in the next edition. It is worthy of note that over a third of the values in the section are new.

In the second half of the book, the efforts to meet the needs of the student of the newer physics are noteworthy. Thus, on p. 73 there is a section, which will frequently be of value for reference, explaining the spectroscopic symbolism such as $3d^6 4S^2$; several such explanatory passages have been added, and the one on p. 99 giving the general formula for inter-plane distances in the general triclinic crystal may be particularly noted.

At this stage of its career the utility of the volume needs no emphasis and one would like to see the price reduced so as to render the book available to the student of limited means who now may be inclined to borrow a library copy instead of securing a copy for his personal use.

E. G.

British Polar Year Expedition, Fort Rae, N.W. Canada, 1932–3. Volume I: *Discussion of Results; Meteorology, Terrestrial Magnetism and Aurora, Atmospheric Electricity*. Pp. xv + 336 + 5 plates and numerous diagrams. Volume II: *Tables; Meteorology, Terrestrial Magnetism, Atmospheric Electricity*. Pp. ix + 228. Published under the direction of the British National Committee for the Polar Year, The Royal Society, Burlington House, London. (London: Percy Lund, Humphries and Co., Ltd., 1937.) Volume I, 21*s.* net; volume II, 15*s.* net.

These two volumes give an admirably full and clear account of the main British contribution to the work of the Second International Polar Year, 1932–3. This great scientific enterprise, successfully accomplished in a time of world economic depression, was a jubilee repetition and extension of the First Polar Year of 1882–3, the main object in each case being to obtain geophysical (mainly geomagnetic and meteorological) observations throughout a complete year simultaneously at a large number of high-latitude, mainly temporary, stations. Each of the cooperating nations maintained one or more stations. In 1882–3 Great Britain and Canada jointly sent an expedition to Fort Rae. In 1932–3 Canada set up its own station at Chesterfield Inlet, and Great Britain, besides reoccupying Fort Rae, sent an important radio expedition to Tromsø, in Norway, whose results have recently been published by the Royal Society in its *Philosophical Transactions*.

The present volumes are, of course, chiefly interesting to the specialist, meteorologist or geomagnetician, and even to him are interesting not so much in themselves as in conjunction with the similar volumes published by other nations for other polar stations. This is because both meteorology and geomagnetism are largely synoptic sciences, requiring the study of great masses of data from a network of stations over the globe. The laboratory physicist, however, would do well, in some leisure hour in the library, to read the charming brief narrative of the expedition given in the introduction, volume I, by the leader of the expedition, Dr J. M. Stagg. Enlivened by occasional humorous touches, it gives an admirable picture of the struggle of the physicist to observe some of Nature's most interesting moods in conditions which Nature herself has made exceptionally difficult. It is in arctic wilds, mostly remote from civilization, that geomagnetic disturbances and aurorae are most intense; there also the meteorological conditions have special interest, the troposphere being far thinner and the stratosphere much warmer than over the equator.

S. C.

Famous American Men of Science, by J. G. CROWTHER. Pp. xvi + 413. (London: Secker and Warburg, Ltd.) Price 15*s.* net.

The investigation of the role of science in modern life is, according to the author, a social duty and this unusual book is his contribution. The American scientists chosen for study are Franklin, Henry, Gibbs and Edison. The theme is that the progress of science is not accidental but is due to the needs of society at the time. Although for the most part the reasoning seems logical, sound and restrained, now and again the author's journalistic and socialistic connexions predominate. For example, he says: "Galileo and Newton discovered their system of mechanics, because the progressive social thought of their time, that of the rising trading classes, already interpreted phenomena quantitatively rather than qualitatively"; or again: "Newton and his discoveries in mathematical astronomy were a product of the urge of the ruling mercantile classes to discover how they could increase their knowledge of the technique of transport, and discover new sources of wealth, and increase their freights and profit."

There are many interesting things in the book concerning the four scientists with whom it is primarily concerned and others. We are told that many persons earned a livelihood by going about and showing Leiden jars, that Franklin predicted aerial warfare, the League of Nations and other modern conceptions and that G. Bernard Shaw was at one time employed by Edison. The book is a useful contribution to the study of the history of science and to sociology.

H. R. L.

Actualités Scientifiques et Industrielles. Under this general heading we have received the monographs listed below. Each is written by an authority on his subject and the treatment is, in general, concise and clear. The publishers are Herman and Co., 6, Rue de la Sorbonne, 6, Paris.

332. M. E. NAHMIAS. *Analyse des Matières Cristallisées au Moyen des Rayons X.* 15 fr.
334. M. RADU TITEICA. *Spectres de Vibration et Structure des Molécules Polyatomiques.* 18 fr.
338. I-V. KOURTSCHATOV. *Le Champ Moléculaire dans les Diélectriques.* 12 fr.
339. J. SOLOMON. *Théorie du Passage des Rayons Cosmiques à Travers la Matière.* 18 fr.
340. *Les Rayons Cosmiques.* (International Conference on Physics, London, 1934.) 10 fr.
341. *Transmutations.* (International Conference on Physics, London, 1934.) 18 fr.
342. *L'État Solide de la Matière.* (International Conference on Physics, London, 1934.) 18 fr.
363. RENÉ FORTRAT. *L'Effet Zeeman dans les Spectres de Bandes.* 12 fr.
365. G. ALLARD. *Polarisation Diélectrique.* 10 fr.
366. GUY EMSCHWILLER. *Les Données Spectrales.* 12 fr.
369. G. GAMOW. *Cinétique des Réactions Nucléaires.* 8 fr.
373. A. FROUMKINE. *Couche Double. Électrocapillarité. Surtension.* 10 fr.
374. P. RUMPF. *La Théorie de l'Ion Amphotère.* 12 fr.
399, 400. R. FREYMANN. *Les Ondes Hertziennes et la Structure Moléculaire.* Part I, 10 fr. Part II, 15 fr.
406. THÉODORE KAHAN. *Théorie de L'Émission des Rayons Alpha à Travers une Double Barrière de Potentiel.* 12 fr.
409. JEAN-LOUIS DESTOUCHES. *La Cinétique Opératorielle.* 18 fr.
411. LOUIS DE BROGLIE. *Nouvelles Recherches sur la Lumière.* 12 fr.
424. F. DUPRÉ LA TOUR. *Le Polymorphisme des Acides Gras.* 14 fr.
457. JACQUES BRILLOUIN. *L'Acoustique et la Construction. Bases de la Technique.* 18 fr.
458. F. LONDON. *Une Conception Nouvelle de la Supra-Conductibilité.* 20 fr.
473. M. P. LACROUTE. *Raies d'Absorption dans les Spectres Stellaires.* 20 fr.
509, 510. MAURICE LETORT. *Les Conceptions Actuelles du Mécanisme des Réactions Chimiques.* Parts I and II, 15 fr. each.

INDEX

Numbers preceded by the letter E *refer to pages in the extra part, bound at the beginning of this volume*

PAGE
Aberration, The knife-edge test for spherical . . . 376
Absorption coefficients, Further experiments on the photographic action of gamma rays and their . . . 1
Absorption spectra and photodissociation of halides and oxyhalides of sulphur, selenium and tellurium . . . 679
Absorption spectra of some carbon and tin halides in the vapour state . . . 568
Adsorbing surface, applied to the temperature dependence of oxygenation and oxidation of a tungsten filament, Thermionic approximations to the gas-covered fraction of an . . . 409
Aggregation of metal atoms on solid surfaces, The migration and . . . E 140
Air, The viscosity of . . . 205
Alkali-halide phosphors containing heavy metals . . . E 40
Alkali metals spontaneously deposited on glass surfaces, The electrical conductivity of thin films of the . . . 89
Alloys, Age-hardening . . . E 103
Alloys, conduction in . . . E 75
Alloys of the copper-zinc system, On the optical constants of . . . 345
Alloys. Part 1: The equilibrium between liquid and solid phases, The phase boundaries in binary . . . 243
Alloys. Part 2: The theory of the α, β phase boundaries, The phase boundaries in binary . . . 250
Alloys. Part 1: Thermal expansion of alloys rich in nickel, An X-ray investigation of pure iron-nickel . . . 17
Alloys. Part 2: Thermal expansion of some further alloys, An X-ray investigation of pure iron-nickel . . . 178
Alloys. Part 3: The thermal expansion of alloys rich in iron, An X-ray investigation of pure iron-nickel . . . 307
Alloys. Part 4: The variation of lattice-parameter with composition, An X-ray investigation of pure iron-nickel . . . 315
Alloys. Part 5: The variation of thermal expansion with composition, An X-ray investigation of pure iron-nickel . . . 323
Alloys, The resistance of palladium and palladium-gold . . . 29
Alloys, The theoretical interpretation of the optical constants of copper-zinc . . . 354
Alloys with disordered and ordered arrangement of atoms. Resistance of . . . E 77
Amalgams, The electrical resistance of manganese . . . 635
Amalgams, The magnetic properties of iron . . . 611
Amalgams, The magnetic properties of manganese . . . 230
Amalgams, The magnetic properties of silver . . . 642
Ametropia by the coincidence optometer, The estimation of . . . 444
Amplifier for investigating the wave form of atmospherics, An aperiodic . . . 654
Anderson, John S.: The measurement of distortion in a gauge protection lens . . . 112
Andrade, E. N. da C., and L. C Tsien: The velocity-distribution in a liquid-into-liquid jet . . . 381
Andrade, E. N. da C., and R. Roscoe: Glide in metal single crystals . . . 152
Appleyard, E. T. S.: Some factors influencing the resistance of thin metal films . . . E 118
Atmospherics, An aperiodic amplifier for investigating the wave form of . . . 654
Atmospherics, Applications of the modulating electrode of television cathode ray tubes in investigations of the wave form of . . . 658

PAGE

Band-systems of GeCl and GeBr, Ultraviolet 532
Band-system of germanium monoxide, The ultraviolet 543
Band-systems of SnBr and SiBr, Ultraviolet 554
Band, William: Thermomagnetic properties of nickel wire. Part 3 14
Barkas, Wilfred W.: Wood-water relationships. Part 3: Molecular sorption of water by Sitka spruce wood 237
Bashford, L. A., *see* Jevons
Bates, L. F., and A. W. Ireland: The magnetic properties of silver amalgams 642
Bates, L. F., and L. C. Tai: The magnetic properties of manganese amalgams 230
Bates, L. F., and P. F. Illsley: The magnetic properties of iron amalgams 611
Bates, L. F., and P. G. Day: The electrical resistance of manganese amalgams 635
Bernamont, J.: Fluctuations in the resistance of thin films E 138
Beta-radiation on gamma-ray measurements made in air, The effect of secondary 338
Boer, J. H. de, and E. J. W. Verwey: Semi-conductors with partially and with completely filled 3*d*-lattice bands E 59
Bond, W. N.: The viscosity of air 205
Borelius, G.: Resistance of alloys with disordered and ordered arrangement of atoms E 77
Bradley, A. J., *see* Bragg
Bragg, W. L., C. Sykes, and A. J. Bradley: A study of the order-disorder transformation E 96
Brass, The energy of the superlattice in β 258
Brentano, J. C. M.: An X-ray goniometer using beams of large aperture for photographically recording crystal-powder reflections 61
Briggs, Allan H.: The estimation of ametropia by the coincidence optometer 444
Brindley, G. W., *see* Hoare
Briscoe, H. V. A., *see* Jevons
Brown, G. Burniston: The mechanism of edge-tone production 508
Brown, G. Burniston: The vortex motion causing edge-tones 493
Buckley, H.: Note on the radiation between two coaxial radiating cylinders 225

Cady, W. G.: Presentation of the fourteenth Duddell Medal to 693
Cady, W. G.: The longitudinal effect in Rochelle salt crystals 646
Campbell, N. R., and R. S. Rivilin: The effect of hydrogen on the time-lag of argon-filled photoelectric cells 12
Carbon and tin halides in the vapour state, Absorption spectra of some 568
Cathode ray tubes in investigations of the wave form of atmospherics, Applications of the modulating electrode of television 658
Chance, W. H. S.: The optical glassworks at Benediktbeuern 433
Chladni figures by means of solid carbon dioxide. Part I: Bars and other metal bodies, The production of 522
Cinematography and for projection with continuously moving films, The use of rotating parallel-plane blocks for 663
Cochlea to phase-reversal in a continuous musical tone, The response of the mammalian 190
Cockburn, R.: A determination of the fundamental types of electron oscillations in a triode valve 38
Colour-vision characteristics of a trichromat, Part 2, The 332
Conduction of electricity in solids, Report of conference on the E 1
Conductivity and photochemical processes in alkali-halide crystals, Electron E 3
Conductivity of a sample of Acheson graphite from 0° to 800° C., The thermal and electrical 419
Conductivity of thin films of indium, The structure and electrical 121
Conductivity of thin films of the alkali metals spontaneously deposited on glass surfaces, The electrical 89

PAGE

Conference on the conduction of electricity in solids, Introduction to the report of . . . E v
Conybeare, J. G. G.: The resistance of palladium and palladium-gold alloys . . . 29
Copper-zinc alloys, The theoretical interpretation of the optical constants of . . . 354
Copper-zinc system, On the optical constants of alloys of the . . . 345
Cosslett, V. E.: The structure and electrical conductivity of thin films of indium . . . 121
Counting impulses at high speeds of counting, A circuit for . . . 85
Cox, H. L., and D. G. Sopwith: The effect of orientation on stresses in single crystals and of random orientation on strength of polycrystalline aggregates . . . 134
Crystals and of random orientation on strength of polycrystalline aggregates, The effect of orientation on stresses in single . . . 134
Crystals, Glide in metal single . . . 152
Crystals of sodium between 120° and 370° K., Intensities of X-ray reflections from single . . . 294
Crystals, The longitudinal effect in Rochelle salt . . . 646
Cuckow, F. W., *see* Preston

Dawton, Ralph H. V. M.: Intensities of X-ray reflections from single crystals of sodium between 120 and 370° K. . . . 294
Day, P. G., *see* Bates
Daylight-factor meter, Demonstration of the portable photoelectric . . . 194
Demonstration of a microscope for use with ultraviolet light, employing a reflecting optical system of aplanatic properties . . . 427
Demonstration of the audible effect of a sudden change of phase in the current supplied to a telephone receiver . . . 194
Demonstration of the portable photoelectric daylight-factor meter . . . 194
Desch, C. H.: Age-hardening alloys . . . E 103
Diamagnetic susceptibilities of dissolved and hydrated salts, The . . . 619
Diffusion, An experimental study of turbulence . . . 479
Distortion in a gauge protection lens, The measurement of . . . 112
Duddell Medal, Presentation to Prof. G. W. Cady of the fourteenth . . . 693

Eclipse of 19 June 1936, Ionospheric conditions during the solar . . . 214
Edge-tone production, The mechanism of . . . 508
Edge-tones, The vortex motion causing . . . 493
Electron conductivity and photochemical processes in alkali-halide crystals . . . E 3
Electron emission from complex surfaces, Secondary- . . . 392
Electron oscillations in a triode valve, A determination of the fundamental types of . . . 38
Electrons in polar crystals, Trapped . . . E 32
Expansion of alloys rich in iron, An X-ray investigation of pure iron-nickel alloys. Part 3: The thermal . . . 307
Expansion of some further alloys, An X-ray investigation of pure iron-nickel alloys. Part 2: Thermal . . . 178
Expansion with composition, An X-ray investigation of pure iron-nickel alloys. Part 5: The variation of thermal . . . 323

Ferromagnetics, The electrical resistance of . . . 67[illegible]
Féry, A.: A study of the electrical properties of thin films of platinum obtained by cathode sputtering in air and other gases (He, N_2, O_2 and H_2) . . . E 136
Films, Conduction in thin metallic . . . E 111
Films, Fluctuations in the resistance of thin . . . E 138
Films of indium, The structure and electrical conductivity of thin . . . 121
Films of platinum obtained by cathode sputtering in air and other gases (He, N_2, O_2 and H_2), A study of the electrical properties of thin . . . E 136
Films of the alkali metals spontaneously deposited on glass surfaces, The electrical conductivity of thin . . . 89

PAGE
Films, Some factors influencing the resistance of thin metal . . . . . E 118
Films, Structural changes during the growth of metal 279
Films, The structure of thin metallic . . . . E 113
Finch, G. I.: The structure of thin metallic films . . . . . . E 113
Fincham coincidence optometer, The development of the 469
Fincham, E. F.: The coincidence optometer 456
Fluorescence of some impurity solids, The effects of temperature on the intensity of . . . . E 46

Gamma-ray measurements made in air, The effect of secondary beta-radiation on 338
Gamma-rays and on their absorption coefficients, Further experiments on the photographic action of 1
GeCl and GeBr, Ultraviolet band-systems of 532
George, Wm. H.: Sensitivity variation of X-ray photographic films . . . 357
Germanium monoxide, The ultraviolet band-system of 543
Glassworks at Benediktbeuern, The optical 433
Gold alloys, The resistance of palladium and palladium- 29
Goniometer using beams of large aperture for photographically recording crystal-powder reflections, An X-ray 61
Graphite from 0° to 800° C., The thermal and electrical conductivity of a sample of Acheson 419
Griffiths, J. H. E.: A circuit for counting impulses at high speeds of counting . 85
Gurney, R. W., and N. F. Mott: Trapped electrons in polar crystals. . . . E 32

Halides and oxyhalides of sulphur, selenium and tellurium, Absorption spectra and photodissociation of 679
Hallpike, C. S., H. Hartridge, and A. F. Rawdon-Smith: The response of the mammalian cochlea to phase-reversal in a continuous musical tone . . 190
Hartridge, H., *see* Hallpike
Hilsch, R.: Alkali-halide phosphors containing heavy metals . . . . . E 40
Hoare, F. E., and G. W. Brindley: The diamagnetic susceptibilities of dissolved and hydrated salts 619
Hussain, S. L., and R. Samuel: Absorption spectra and photodissociation of halides and oxyhalides of sulphur, selenium and tellurium 679
Hydrogen by palladium, The effect of pressure and temperature on the occlusion of 587
Hydrogen system, The palladium- 603

Illsley, P. F., *see* Bates
Indium, The structure and electrical conductivity of thin films of 121
Ionospheric conditions during the solar eclipse of 19 June 1936 214
Ireland, A. W., *see* Bates
Iron amalgams, The magnetic properties of 611
Iron-nickel alloys. Part 1: Thermal expansion of alloys rich in nickel, An X-ray investigation of pure 17
Iron-nickel alloys. Part 2: Thermal expansion of some further alloys, An X-ray investigation of pure 178
Iron-nickel alloys. Part 3: The thermal expansion of alloys rich in iron, An X-ray investigation of pure 307
Iron-nickel alloys. Part 4: The variation of lattice-parameter with composition, An X-ray investigation of pure 315
Iron-nickel alloys. Part 5: The variation of thermal expansion with composition, An X-ray investigation of pure 323

Jet, The velocity-distribution in a liquid-into-liquid 381

PAGE

Jevons, W., L. A. Bashford, and H. V. A. Briscoe: Ultraviolet band-systems of GeCl and GeBr 532
Jevons, W., L. A. Bashford, and H. V. A. Briscoe: The ultraviolet band-system of germanium monoxide 543
Jevons, W., and L. A. Bashford: Ultraviolet band-systems of SnBr and SiBr . 554
Johnson, M. C., and F. A. Vick: Thermionic approximations to the gas-covered fraction of an adsorbing surface, applied to the temperature dependence of oxygenation and oxidation of a tungsten filament 409
Jones, John Idwal, *see* Owen
Jones, H.: The phase boundaries in binary alloys. Part 1: The equilibrium between liquid and solid phases 243
Jones, H.: The phase boundaries in binary alloys. Part 2: The theory of the α, β phase boundaries 250

Kingslake, R.: The knife-edge test for spherical aberration 376

Lennard-Jones, J. E.: The migration and aggregation of metal atoms on solid surfaces . . . . E 140
Lens, The measurement of distortion in a gauge protection 112
Lightning discharges, Rapid variations in the magnetic field produced by . . 364
Lovell, A. C. B.: The electrical conductivity of thin films of the alkali metals spontaneously deposited on glass surfaces 89
Lowery, H., H. Wilkinson, and D. L. Smare: On the optical constants of alloys of the copper-zinc system 345

Magnetic field produced by lightning discharges, Rapid variations in the . . 364
Magnetic properties of iron amalgams, The 611
Magnetic properties of manganese amalgams, The 230
Magnetic properties of silver amalgams, The 642
Manganese amalgams, The electrical resistance of 636
Manganese amalgams, The magnetic properties of 230
Microscope for use with ultraviolet light, employing a reflecting optical system of aplanatic properties, Demonstration of a 427
Migration and aggregation of metal atoms on solid surfaces, The . . . . E 140
Mott, N. F.: Introduction to the report of conference on the conduction of electricity in solids . . . . E v
Mott, N. F., *see* Gurney
Mott, N. F.: The energy of the superlattice in β brass 258
Mott, N. F.: The theoretical interpretation of the optical constants of copper-zinc alloys 354
Musical tone, The response of the mammalian cochlea to phase-reversal in a continuous 190
Myers, D. M.: The division of primary electron current between grid and anode of a triode 264

Naismith, R.: Ionospheric conditions during the solar eclipse of 19 June 1936 . 214
Nelson, J. H.: The colour-vision characteristics of a trichromat, Part 2 . . . 332
Nickel alloys. Part 3: The thermal expansion of alloys rich in iron, An X-ray investigation of pure iron- 307
Nickel alloys. Part 4: The variation of lattice-parameter with composition, An X-ray investigation of pure iron- 315
Nickel alloys. Part 5: The variation of thermal expansion with composition, An X-ray investigation of pure iron- 323
Nickel wire. Part 3: Thermomagnetic properties of 14
Nickel, An X-ray investigation of pure iron-nickel alloys. Part 1: Thermal expansion of alloys rich in 17

PAGE

Non-metals, conduction in . . . E 1
Norinder, Harald: Rapid variations in the magnetic field produced by lightning discharges . . . 364

Obituary notices . . . 694
Occlusion of hydrogen by palladium, The effect of pressure and temperature on the 587
Optical constants of alloys of the copper-zinc system, On the . . . 345
Optical constants of copper-zinc alloys, The theoretical interpretation of the . 354
Optometer, The coincidence . . . 456
Optometer, The development of the Fincham coincidence . . . 469
Optometer, The estimation of ametropia by the coincidence . . . 444
Owen, E. A., and E. L. Yates: An X-ray investigation of pure iron-nickel alloys. Part 1: Thermal expansion of alloys rich in nickel . . . 17
Owen, E. A., and E. L. Yates: An X-ray investigation of pure iron-nickel alloys. Part 2: Thermal expansion of some further alloys . . . 178
Owen, E. A., and E. L. Yates: An X-ray investigation of pure iron-nickel alloys. Part 3: The thermal expansion of alloys rich in iron . . . 307
Owen, E. A., E. L. Yates, and A. H. Sully: An X-ray investigation of pure iron-nickel alloys. Part 4: The variation of lattice-parameter with composition . 315
Owen, E. A., E. L. Yates, and A. H. Sully: An X-ray investigation of pure iron-nickel alloys. Part 5: The variation of thermal expansion with composition 323
Owen, E. A., and John Idwal Jones: The effect of pressure and temperature on the occlusion of hydrogen by palladium . . . 587
Owen, E. A., and John Idwal Jones: The palladium-hydrogen system . . 603
Oxygenation and oxidation of a tungsten filament, Thermionic approximations to the gas-covered fraction of an adsorbing surface, applied to the temperature dependence of . . . 409

Palladium and palladium-gold alloys, The resistance of . . . 29
Palladium, The effect of pressure and temperature on the occlusion of hydrogen by 587
Palladium-hydrogen system, The . . . 603
Parker, R. C.: The smoke method of measuring supersonic velocities . . 95
Parti, Y. P., and R. Samuel: Absorption spectra of some carbon and tin halides in the vapour state . . . 568
Phosphors containing heavy metals, Alkali-halide . . . E 40
Photochemical processes in alkali-halide crystals, Electron conductivity and . E 3
Photodissociation of halides and oxyhalides of sulphur, selenium and tellurium, Absorption spectra and . . . 679
Photoelectric cells, The effect of hydrogen on the time-lag of argon-filled . . 12
Photoelectric daylight-factor meter, Demonstration of the portable . . . 194
Photographic films, Sensitivity variation of X-ray . . . 357
Photometric test plates . . . 105
Pitt, F. H. G., *see* Wright
Platinum obtained by cathode sputtering in air and other gases (He, N_2, O_2 and H_2), A study of the electrical properties of thin films of . . . E 136
Pohl, R. W.: Electron conductivity and photochemical processes in alkali-halide crystals . . . E 3
Potter, H. H.: The electrical resistance of ferromagnetics . . . 671
Powell, R. W.: The thermal and electrical conductivity of a sample of Acheson graphite from 0° to 800° C. . . . 419
Preston, J. S., and F. W. Cuckow: A photoelectric spectrophotometer of high accuracy . . . 189

Quarrell, A. G.: Structural changes during the growth of metal films . . 279

Radiation between two coaxial radiating cylinders, Note on the . . . 225

PAGE
Randall, J. T.: The effects of temperature on the intensity of fluorescence of some impurity solids . . . . E 46
Rawdon-Smith, A. F., *see* Hallpike
Reason, R. E.: The development of the Fincham coincidence optometer . . 469
Resistance of alloys with disordered and ordered arrangement of atoms . . E 77
Resistance of ferromagnetics, The electrical 671
Resistance of manganese amalgams, The electrical 635
Resistance of palladium and palladium-gold alloys, The 29
Resistance of thin films, Fluctuations in the . . . . E 138
Resistance of thin metal films, Some factors influencing the . . . . . E 118
Reviews of books 78, 198, 326, 429, 629
Richardson, E. G.: An experimental study of turbulence diffusion . . . 479
Rivlin, R. S., *see* Campbell
Rochelle-salt crystals, The longitudinal effect in 646
Rogers, J. S.: Further experiments on the photographic action of gamma rays and on their absorption coefficients 1
Roscoe, R., *see* Andrade

Samuel, R., *see* Hussain
Samuel, R., *see* Y. P. Parti
Selenium and tellurium, Absorption spectra and photodissociation of halides and oxyhalides of sulphur 679
Semi-conductors with partially and with completely filled 3*d*-lattice bands . E 59
SiBr, Ultraviolet band-systems of SnBr and 554
Silver amalgams, The magnetic properties of 642
Smare, D. L., *see* Lowery
SnBr and SiBr, Ultraviolet band-systems of 554
Sopwith, D. G., *see* Cox
Sodium between 120 and 370° K., Intensities of X-ray reflections from single crystals of 294
Sorption of water by Sitka spruce wood, Wood-water relationships. Part 3: Molecular 237
Spectra of some carbon and tin halides in the vapour state, Absorption . . 568
Spectrophotometer of high accuracy, A photoelectric 189
Spherical aberration, The knife-edge test for 376
Sulley, A. H., *see* Owen
Sulphur, selenium and tellurium, Absorption spectra and photodissociation of halides and oxyhalides of 679
Superlattice in β brass, The energy of the 258
Supersonic velocities, The smoke method of measuring 95
Surfaces, The migration and aggregation of metal atoms on solid . . . E 140
Sykes, C., *see* Bragg

Tai, L. C., *see* Bates
Taylor, A. K.: Photometric test plates 105
Taylor, H. Dennis: The use of rotating parallel-plane glass blocks for cinematography and for projection with continuously moving films 663
Telephone receiver, Demonstration of the audible effect of a sudden change of phase in the current supplied to a 194
Tellurium, Absorption spectra and photodissociation of halides and oxyhalides of sulphur, selenium and 679
Thermomagnetic properties of nickel wire. Part 3 14
Tin halides in the vapour state, Absorption spectra of some carbon and . . 568
Tin, *see* Sn
Transformation, A study of the order-disorder . . . . E 96
Treloar, L. R. G.: Secondary-electron emission from complex surfaces . . 392

PAGE
Trichromat. The colour-vision characteristics of a 332
Trichromats, The saturation-discrimination of two 329
Triode, The division of primary electron current between grid and anode of a . 264
Triode valve, A determination of the fundamental types of electron oscillations in a 38
Tsien, L. C., *see* Andrade
Tungsten filament, Thermionic approximations to the gas-covered fraction of an adsorbing surface, applied to the temperature dependence of oxygenation and oxidation of a 409

Ultraviolet band-systems of GeCl and GeBr 532
Ultraviolet band-system of germanium monoxide, The 543
Ultraviolet band-systems of SnBr and SiBr 554
Ultraviolet light, employing a reflecting optical system of aplanatic properties, Demonstration of a microscope for use with 427

Verwey, E. J. W., *see* Boer
Vick, F. A., *see* Johnson
Viscosity of air, The 205
Vortex motion causing edge-tones, The 493

Waller, Mary D.: The production of Chladni figures by means of solid carbon dioxide. Part 1: Bars and other metal bodies 522
Webster, H. C.: An aperiodic amplifier for investigating the wave-form of atmospherics 654
Webster, H. C.: Applications of the modulating electrode of television cathode-ray tubes in investigations of the wave-form of atmospherics 658
Wilkinson, H., *see* Lowery
Wilson, C. W.: The effect of secondary beta-radiation on gamma-ray measurements made in air 338
Wood-water relationships. Part 3: Molecular sorption of water by Sitka spruce wood 237
Wright, W. D., and F. H. G. Pitt: The saturation-discrimination of two trichromats 329

X-ray goniometer using beams of large aperture for photographically recording crystal-powder reflections, An 61
X-ray investigation of pure iron-nickel alloys. Part 1: Thermal expansion of alloys rich in nickel, An 17
X-ray investigation of pure iron-nickel alloys. Part 2: Thermal expansion of some further alloys, An 178
X-ray investigation of pure iron-nickel alloys. Part 3: The thermal expansion of alloys rich in iron, An 307
X-ray investigation of pure iron-nickel alloys. Part 4: The variation of lattice-parameter with composition, An 315
X-ray investigation of pure iron-nickel alloys. Part 5: The variation of thermal expansion with composition, An 323
X-ray reflections from single crystals of sodium between 120° and 370° K., Intensities of 294

Yates, E. L., *see* Owen

Zinc alloys, The theoretical interpretation of the optical constants of copper . 354
Zinc system, On the optical constants of alloys of the copper 345

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